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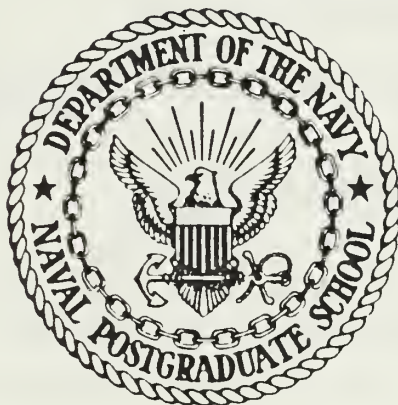
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THESIS

PRELIMINARY STUDIES OF A TECHNIQUE FOR MEASURING
THE
VOLUME BACKSCATTERING FROM SEDIMENTS

by

Federico Rene Diaz

SEPTEMBER 1986

Thesis Advisors:

James V. Sanders
Alan B. Coppens

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sound speed
reflection coefficient
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gravel (aggregate)
beam pattern
beamwidth
near field
density

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Preliminary Studies of a Technique for Measuring
the
Volume Backscattering from Sediments

by

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requirements for the degree of

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ABSTRACT

An experimental study was performed to devise a technique for measuring the volume backscattering from sediments. This experimental technique has never been performed in the laboratory. The volume backscattering was to be determined by comparing the echoes returned from the sediment with the echo returned from the water/air interface. Measurements made on echoes returned from the water/air interface indicated that the apparatus, data acquisition system, and analysis system were performing correctly. Two types of sediments (fine sand and aggregate gravel) were used. The fine sand did not produce measureable volume backscattering and the aggregate showed results that depended on the region of sediment ensonified. It is recommended that a sediment more homogeneous than the aggregate, but with more backscattering than the fine sand be used in future studies.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

TABLE OF CONTENTS

I.	INTRODUCTION	10
II.	BACKGROUND	14
III.	EXPERIMENTAL DESIGN	15
	A. MATERIAL SELECTED	15
	B. TEST TANKS	15
	C. ELECTRONIC EQUIPMENT	15
	D. MEASUREMENT OF THE PROPERTIES OF THE RECEIVED SIGNAL	16
	1. Effects of the transmitting electronics	16
	2. Effects of the transducer	16
	3. Effects of the reflective properties of the sediment	17
	4. Effects of the receiving electronics	17
	E. DIGITAL DATA ACQUISITION AND PROCESSING	18
	F. DIAGNOSTIC TESTING OF THE EXPERIMENTAL SYSTEM	18
IV.	PRELIMINARY MEASUREMENTS	29
	A. WATER	29
	B. SEDIMENTS	29
	1. Physical properties	29
	2. Sound speed	30
	C. TESTS PERFORMED ON TRANSDUCER	30
	1. Beam pattern and beamwidth	30
	2. Near field	32
	3. Pressure reflection coefficient	33
	D. SUMMARY OF PRELIMINARY MEASUREMENTS	34
	1. Test tank criteria	34
	2. Sediment criteria	34

V. RESULTS 43

VI. CONCLUSIONS AND RECOMMENDATIONS 44

LIST OF REFERENCES 45

APPENDIX A: COMPUTER PROGRAMS 46

APPENDIX B: PRELIMINARY TESTS 54

APPENDIX C: REFLECTION COEFFICIENT AND DENSITY
MEASUREMENTS 60

APPENDIX D: RESULTS 62

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LIST OF FIGURES

1.1	Basic Acoustic Quantities	11
1.2	Grain Sizes	12
1.3	Cross Section in Region $ka \sim 1$	13
3.1	Experimental Tray Setup	20
3.2	Electronic Equipment Schematic	21
3.3	T/R Switch Circuit Schematic	22
3.4	High Pass Filter Schematic	23
3.5	Water Reflection Arrangement	24
3.6	Sediment Reflection Arrangement	25
3.7	Water and Sediment Echo Envelopes	26
3.8	Averaged Squared Voltages in a Bin (Tail Portion)	27
3.9	Averaged Squared Voltages of the Local Maxima	28
4.1	Directivity Pattern for A503 LC10 Receiver	35
4.2	Model Geometry for Speed of Sound in Water	36
4.3	Distance versus Time (Water)	37
4.4	Model Geometry for Speed of Sound in Aggregate	38
4.5	Distance versus Time (Aggregate)	39
4.6	Beam Pattern for F-41 Transducer (Units in dB)	40
4.7	Extent of the Near Field	41
4.8	Model Geometry for Pressure Reflection Coefficient	42

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I. INTRODUCTION

The basic problem of any echo-formation model designed to study the properties of the ocean bottom is to predict the shape of the echo from the ocean bottom. The important geometric quantities, beam angle θ , range R , bottom roughness η , and length scale L , are shown in Figure 1.1. Additional parameters are acoustic wavelength λ , wavenumber $k = 2\pi / \lambda$, and frequency $f = c / \lambda$, where c is the speed of sound in water.

A sound returning from a sedimentary bottom is subject to three types of reflection or scattering: 1) coherent reflection from the bottom, 2) incoherent scattering from the surface irregularities of the bottom, and 3) incoherent scattering from within the volume of the sediment due to the irregular matrix of the sediment. Physically, 3) is independent of 1) and 2) except for the reduction in acoustic amplitude caused by reflection at the surface; once the sound has penetrated the seawater/sediment interface, the existence of the interface has no effect on the transmitted sound wave (Clarke, Proni, Seem, Tsai, 1984).

The bottom echo model as presently formulated by Atlantic Oceanographic and Meteorological Laboratory (AOML), assumes a Raleigh scattering model for scattering of acoustic waves of wave number k from the individual grains within the sediment. For the model, the bottom is assumed to be composed of uniform sediment with grains of radius " a ". Use of the Raleigh scattering approximation requires the grains to be very small compared to wavelength ($ka \ll 1$) as suggested in Figure 1.2.

Figure 1.3 shows the complicated nature of the acoustic cross section for backscattering for $ka \sim 1$ for spherical particles. It has been hypothesized that the ensemble averaged scattering from a collection of irregular shaped sediment particles has a simple form, but the difficulty of incorporating even a simple cross section function into a realistic theory of sediment scattering is formidable.

The direct measurement of the backscattering cross section of bulk sediments for a range of frequencies and grain sizes can be used as input to any echo formation model. The values of backscatter versus frequency can also be used to constrain and test theoretical models of acoustic backscattering from bulk sedimentary materials.

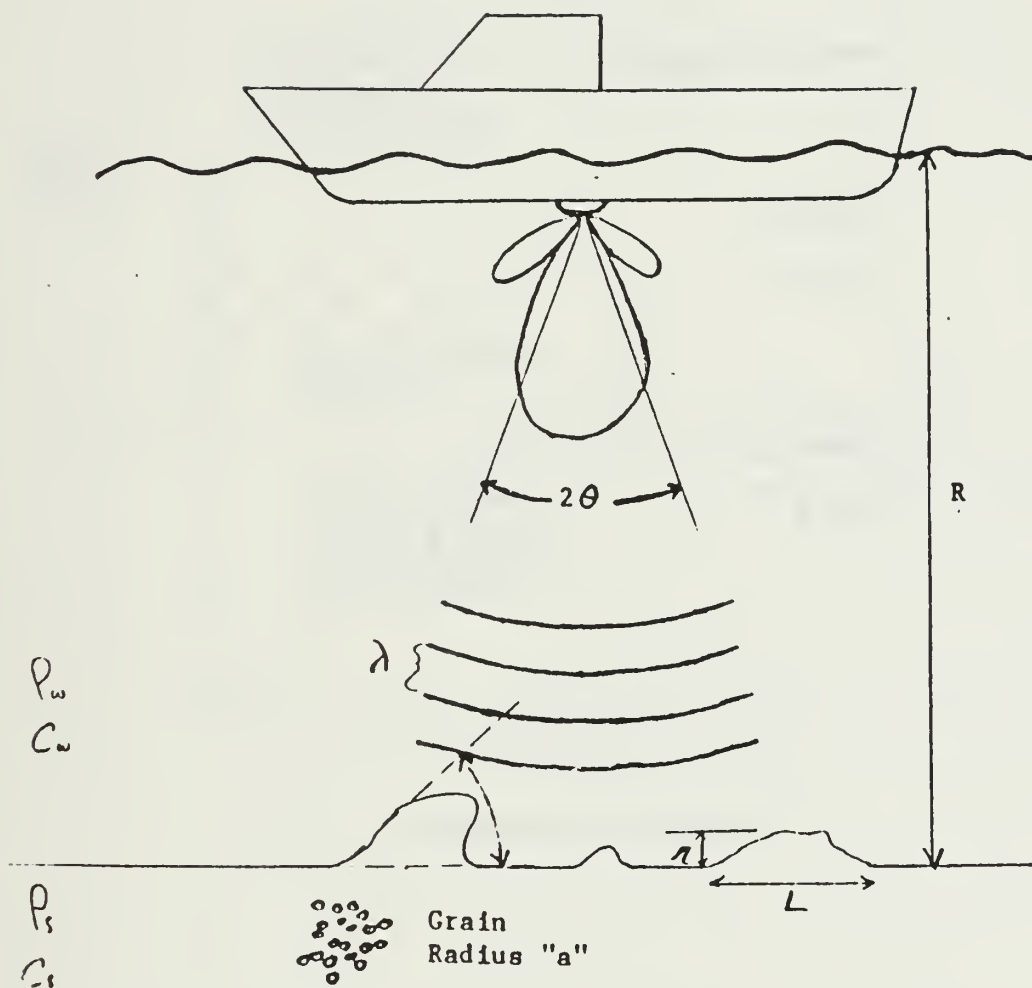


Figure 1.1 Basic Acoustic Quantities.

PHYSICAL SEDIMENT



ACOUSTIC

$ka \ll 1$



ACOUSTIC

$ka \approx 1$

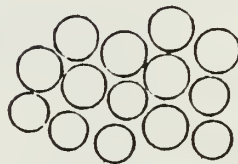


Figure 1.2 Grain Sizes.

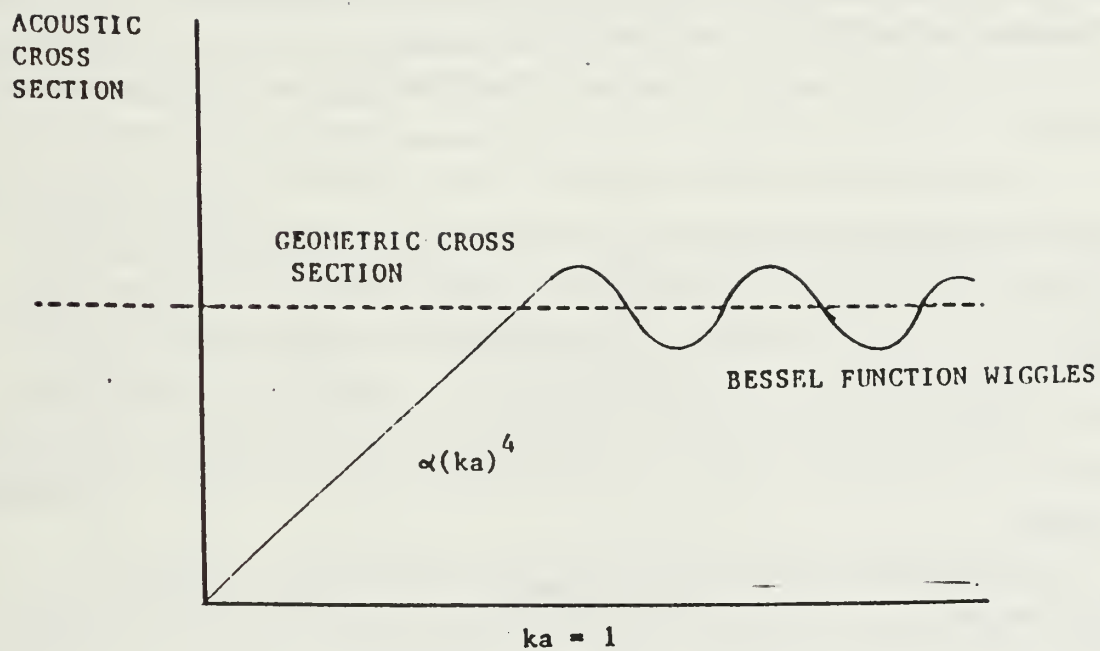


Figure 1.3 Cross Section in Region $ka \sim 1$.

II. BACKGROUND

In the Summer of 1984, a joint program for investigating the mechanism of the formation of acoustic bottom echoes was initiated by the Office of Charting and Geodetic Services (CGS), National Ocean Service (NOS) and by the Atlantic Oceanographic and Meteorological Laboratory (AOML) of the Environmental Research Laboratories (ERL) of the National Oceanic and Atmospheric Administration (NOAA). The objective of this research was to obtain a better understanding of the complex interaction of sound, including its transmission and reflection, with the diverse types of bottoms encountered in U.S. coastal waters.

A major tool of the CGS is the acoustic echo sounder which is used to obtain accurate bottom depth information for the construction of nautical charts. More recent technological innovations include the use of two-frequency, two beam-width echo sounders and multiple-beam bathymetric swath survey systems (BS³ and Sea Beam) as well as enhanced digital recording systems. To understand the limitations and possibilities of these instruments, a good empirically tested model, or perhaps models, of the formation of echoes arising from bottom sound scattering or reflection is needed.

An additional benefit that could result from a theoretical and empirical understanding of the acoustic echo formation process would be the ability to classify sediment on the basis of the echo waveform. This ability would permit nautical charts to contain greatly expanded information about the bottom type. Exploration of the U.S. Exclusive Economic Zone (EEZ) would also be enhanced by a remote-classification ability.

III. EXPERIMENTAL DESIGN

A. MATERIAL SELECTED

Two materials, #30 Monterey fine sand for a fine grain sediment and Monterey Aquarium #2 for a rough gravel sediment, were used. To remove trapped air bubbles from the sediment, the sediment/water mixture was vigorously mixed by pumping a high-speed jet of bubble-free water into the mixture until no further bubbles could be seen rising from the agitated sediment. The sediment was then left in water for two to three days to allow any remaining air bubbles to dissolve. Bleach was added to the water to control biologic growth.

B. TEST TANKS

Initial experiments were conducted in a steel-bound glass tank, measuring 70 cm x 70 cm x 60 cm. This tank was filled with 50 cm of sediment below 20 cm of water.

A second tank, constructed of wood and measuring 3 m x 1 m x 1 m, was used to hold the #30 fine sand sediment. A sediment layer of 40 cm was used for the experiments. The sediment surface was kept smooth and flat throughout the entire experiment.

A third facility consisting of a wooden tray, measuring 60 cm x 60 cm x 122 cm, was fabricated to hold about 90 cm of aggregate Aquarium #2. This tank was lowered and suspended 50 to 100 cm below the water surface of the NPS anechoic tank, Figure 3.1.

C. ELECTRONIC EQUIPMENT

A schematic drawing of the equipment configuration is shown in Figure 3.2. All components were off-the-shelf.

The output from a General Radio Model 1310 oscillator with a nominal frequency of 185 kHz was fed simultaneously into Hewlett-Packard 5233L frequency counter and a General Radio Type 396-A Tone Burst Generator to generate 16- or 32-cycle pulses. The output then passed through a Hewlett-Packard 467-A Power Amplifier set for unit amplification and a Datasonics Transmit/ Receive (T/R) switch, (Circuit Diagram, Figure 3.3). Before being fed to the transducer, the input signal was used to trigger a Nicolet Model 3091 Digital Oscilloscope.

The transducer, an F-41 circular-piston type with a 8.8 cm diameter active face and a thickness of 4.4 cm, was used as both transmitter and receiver. Its resonance frequency was 185 kHz. At this frequency, the 16-cycle pulse had a 13.3-cm pulse length in water, and the 32-cycle pulse twice that.

The received signal was amplified 20 dB by a Hewlett-Packard 465-A preamplifier, passed through a Spencer Kennedy Laboratories, Inc. Model 302 variable electronic filter (set at 136.0 kHz high pass) to eliminate low frequency noise, and then passed to the digital oscilloscope where the digital output was stored for later analysis.

Initially, ringing within the T/R switch caused problems. After consultation and investigation by technicians, it was concluded that there were problems with the diodes within the network of the T/R switch. Replacement of the diodes alleviated, but did not solve the problem. A high pass filter, placed externally to the T/R switch, was then fabricated by the electronics technicians of the Physics Department to suppress the 21 to 28 kHz transient that remained after replacement of the diodes. The circuit diagram for this high pass filter is shown in Figure 3.4.

D. MEASUREMENT OF THE PROPERTIES OF THE RECEIVED SIGNAL

The received signal displayed on the digital oscilloscope consisted of a 16- or 32-cycle, 185 kHz pulse modified by 1) the transmitting electronics (including the T/R switch), 2) the transmitting properties of the transducer, 3) the reflective properties of the sediment, 4) the receiving properties of the transducer, and 5) the receiving electronics. Since it was desired to measure the effects of the sediment on the pulse, the effects of the other mechanisms had to be determined by observing the received signal in the absence of any contribution from the sediment.

1. Effects of the transmitting electronics

The direct observation of the electrical signal applied to the transducer showed that (once the problems with the T/R switch were rectified) the signal was a clean square wave. This demonstrated that the transmitting electronics had negligible effect on the received signal.

2. Effects of the transducer

Since the transducer is a resonant system with damping, the square electrical pulse was transformed into an acoustic pulse with an exponential rise, a flattened top and an exponential decay.

To determine the waveform emitted by the transducer, the F-41 transducer was leveled and then clamped, with its active face pointing upward, to a vertical shaft, which was used to lower the transducer to a pre-determined depth below the surface in the anechoic tank (Figure 3.5). The signal received after reflection from the water/air interface should be an accurate representation of the signal emitted by the transducer. A typical envelope of this signal is shown in Figure 3.7, where a long tone burst was used to display the 32-cycle exponential rise and fall of the pulse envelope.

3. Effects of the reflective properties of the sediment

Reverberation within the sediment altered the exponential decay of the pulse.

For the purposes of sediment echo measurements, the F-41 was leveled and clamped to the vertical shaft to ensound the sediment within a wooden tray suspended in the anechoic tank. The most accurate means of leveling the transducer was to laterally tilt the vertical shaft (with the F-41 attached) until the best possible waveform and largest amplitude were observed on the digital oscilloscope (Figure 3.6).

The transducer was moved horizontally (2 to 3 cm) between data sets to introduce variation in the propagation geometry and thereby provided a more varied ensemble for waveform averaging. The transducer was not moved after each sample, as requested by AOML, as it made data acquisition too time consuming.

4. Effects of the receiving electronics

An analog signal is characterized by continuous voltage variations. The Nicholet 3091 Digital oscilloscope converts the analog signal into discrete, digitized voltages and displays the resulting waveform as discrete points.

At a signal frequency of 185 kHz, a sampling rate of 1 μ s gives only 5.4 samples per period, which is not fast enough to give an accurate display of the waveform (Figure 3.7). However, observations showed that there was natural "jitter" in the triggering of the scope so that for consecutive pulses, the scope would sample different parts of the waveform. To obtain an accurate representation of the received waveform, a large number of waveforms were sampled and the results stored. If sufficient "jitter" is present, the voltages stored in a given bin should vary between the maximum and minimum voltage in the waveform at the time corresponding to the bin. Squaring and averaging the voltages in each bin for a large number of samples should give an accurate representation of the waveform envelope.

The major goal of this experimental project was to determine the effects of reverberation in the sediment by accurately measuring the difference in the decay time

for the "tail" of the reflected pulse from the sediment and the reflected pulse from the water/air interface.

E. DIGITAL DATA ACQUISITION AND PROCESSING

Digital data were stored in the digital oscilloscope and then "dumped" to an HP-86 desktop computer. The digitized data were then squared and averaged over many pulses (i.e., 50 to 100 waveforms per set) and stored on disk. The averaging window was chosen to begin at the starting time of the exponential decay. The data were processed in two ways:

- (1.) The natural logarithm of the averaged squared voltages in each bin was plotted versus time (Figure 3.8).
- (2.) The natural logarithm of the averaged squared voltages of the local maxima were plotted versus time (Figure 3.9).

The following computer programs were written on HP software using an HP-86 desktop computer.

THIESE 1	= Data acquisition program
MAXI	= Determination of local maxima
PLOT	= Plots all averaged points as a function of time.
PLOT-1	= Plots local maxima as a function of time and determines slope of the line.

These programs are shown in Appendix A.

F. DIAGNOSTIC TESTING OF THE EXPERIMENTAL SYSTEM

1. The averaging program was verified by connecting a simple RLC series circuit in place of the transducer and T/R switch to produce a waveform similar to that produced by the F-41 transducer, but at 5 kHz. Using the data acquisition equipment, the data were squared and averaged over several pulses and the results were compared to the voltage readings manually recorded using the built-in curser on the 3091. The comparison was excellent.

2. The echo received from the water/air surface were observed on the Nicholet 3091 to determine if sufficient natural "jitter" exists to allow accurate measurements of the 185 kHz signal. Five data sets with an increasing number of waveforms were stored.

Set 1 - 5 waveforms

Set 2 - 10 waveforms

Set 3 - 25 waveforms

Set 4 - 50 waveforms

Set 5 - 100 waveforms

The voltages for each set were squared and averaged. The logarithm (LN) of each average was plotted as a function of time (bin number). When the number of waveforms used were not sufficient, the scatter on this plot was significant. If enough waveforms are used the scatter on the plot should decrease until the scatter becomes constant with the increasing number of waveforms. The results of this test showed that 50 waveforms were the maximum number required for each data set.

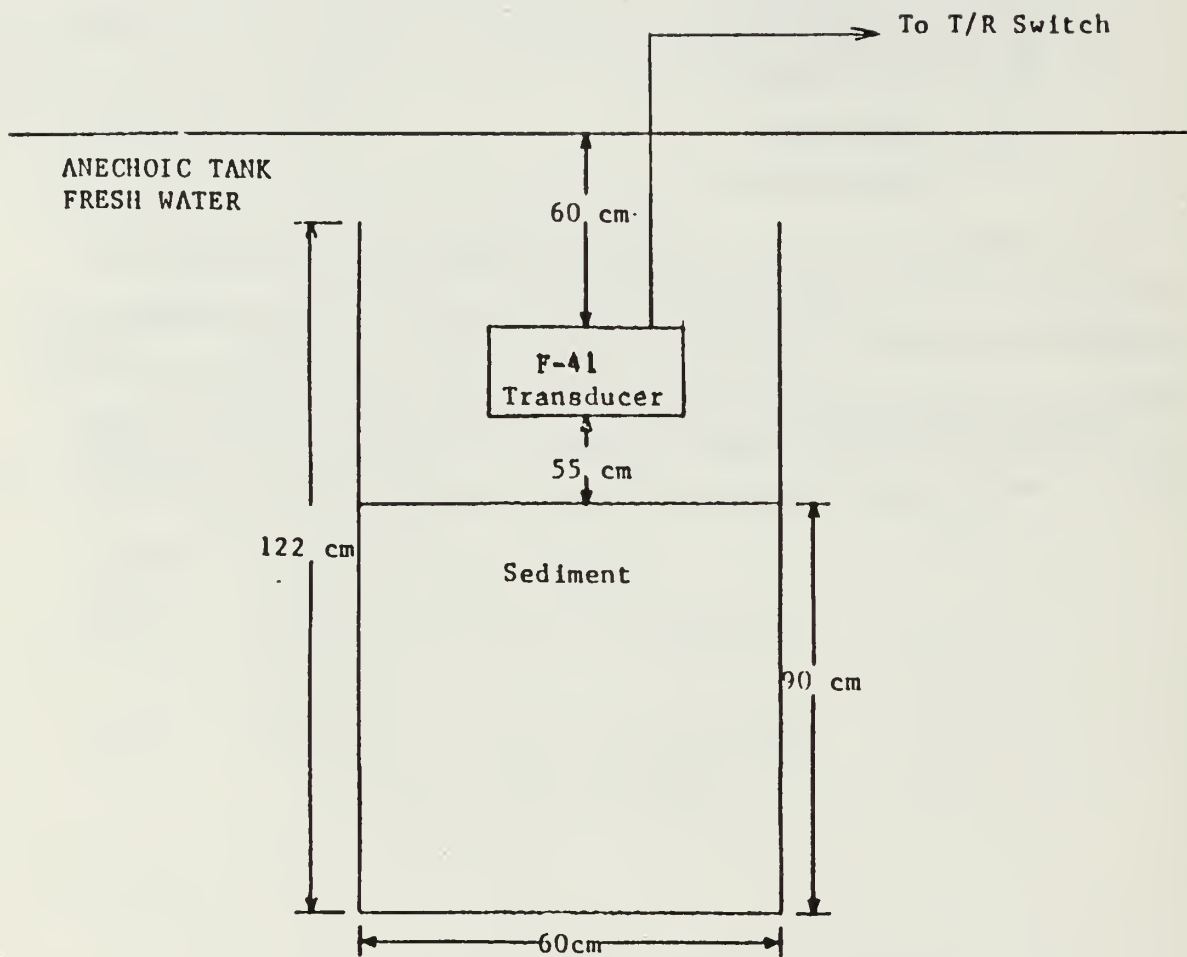


Figure 3.1 Experimental Tray Setup.

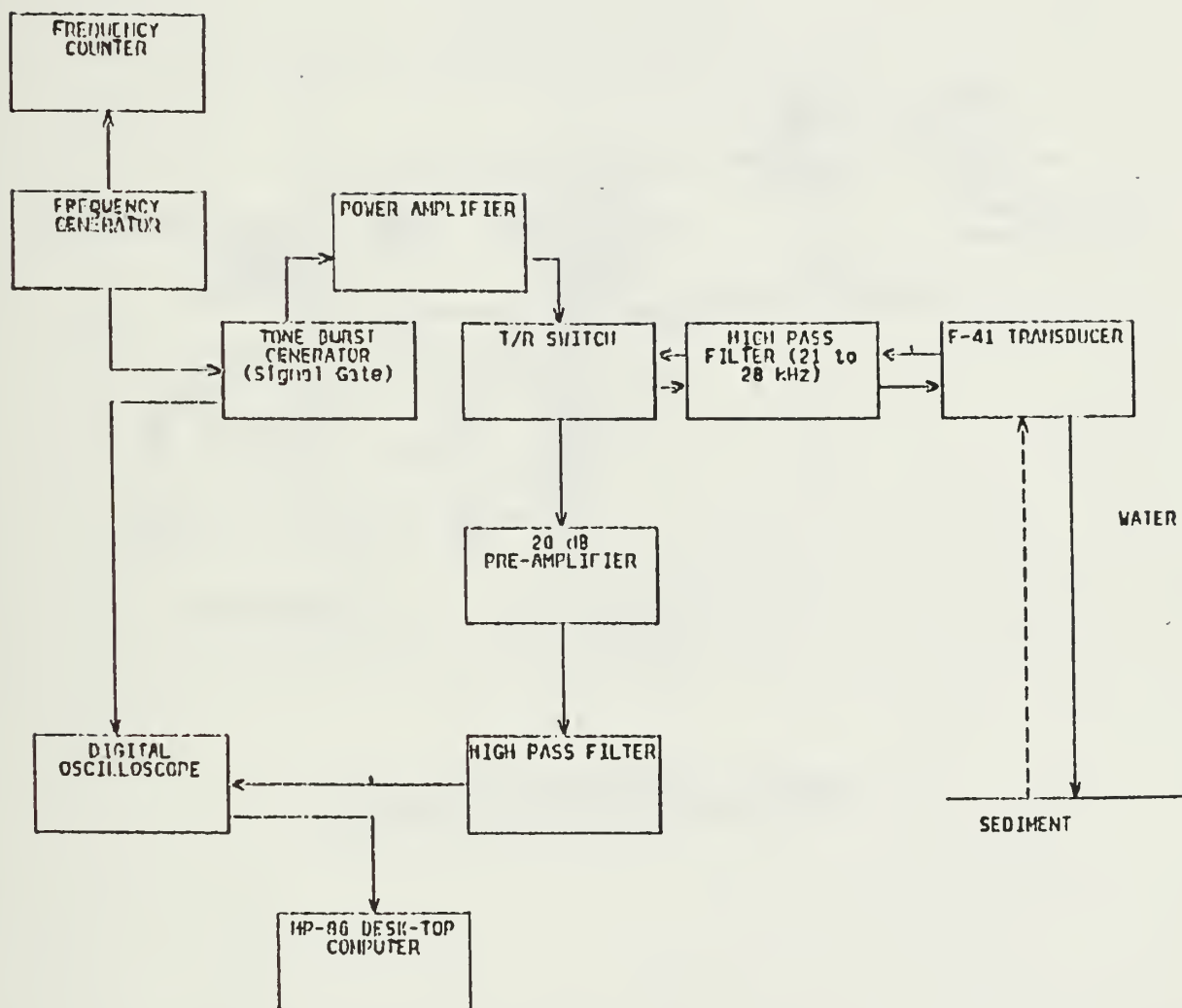


Figure 3.2 Electronic Equipment Schematic.

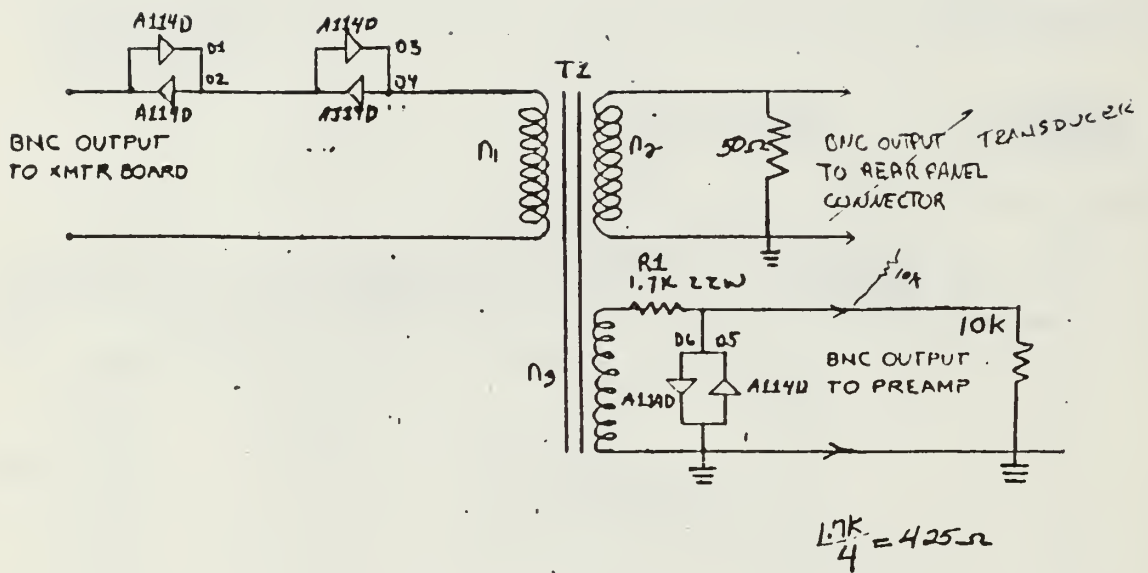
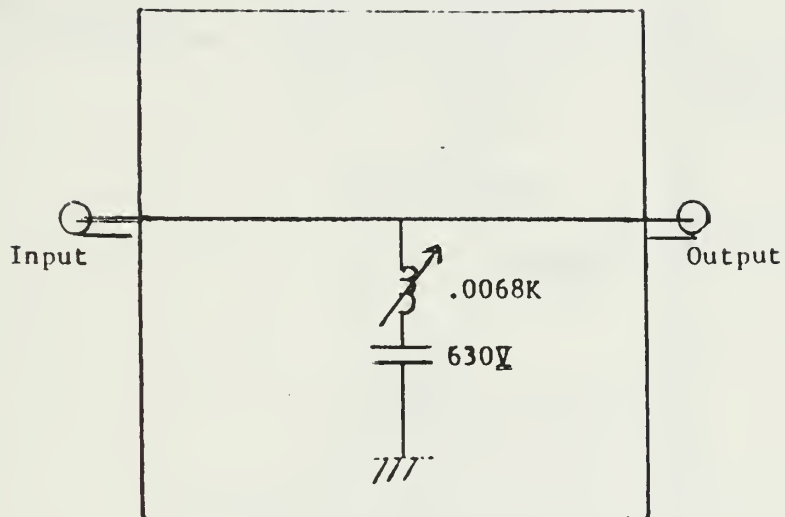


Figure 3.3 T/R Switch Circuit Schematic.



21 - 28 kHz
Notch Filter

Figure 3.4 High Pass Filter Schematic.

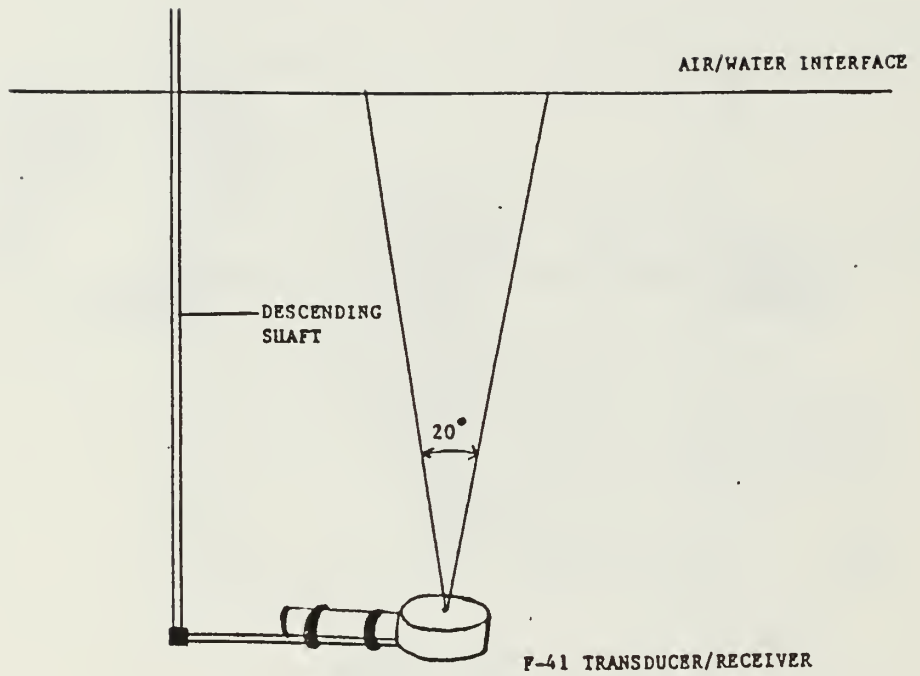


Figure 3.5 Water Reflection Arrangement.

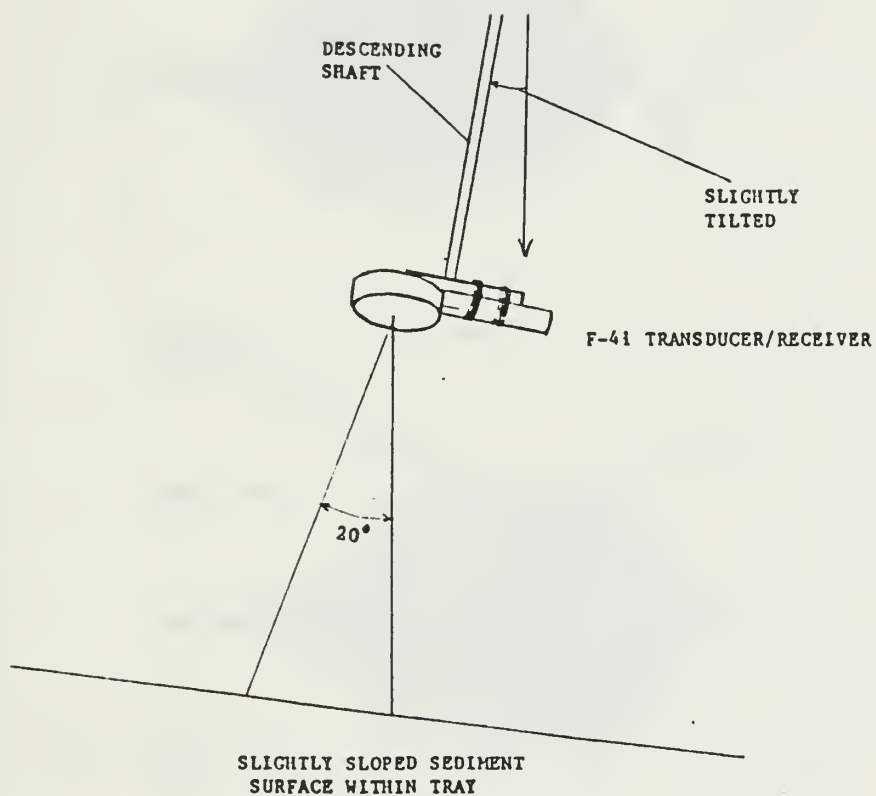


Figure 3.6 Sediment Reflection Arrangement.

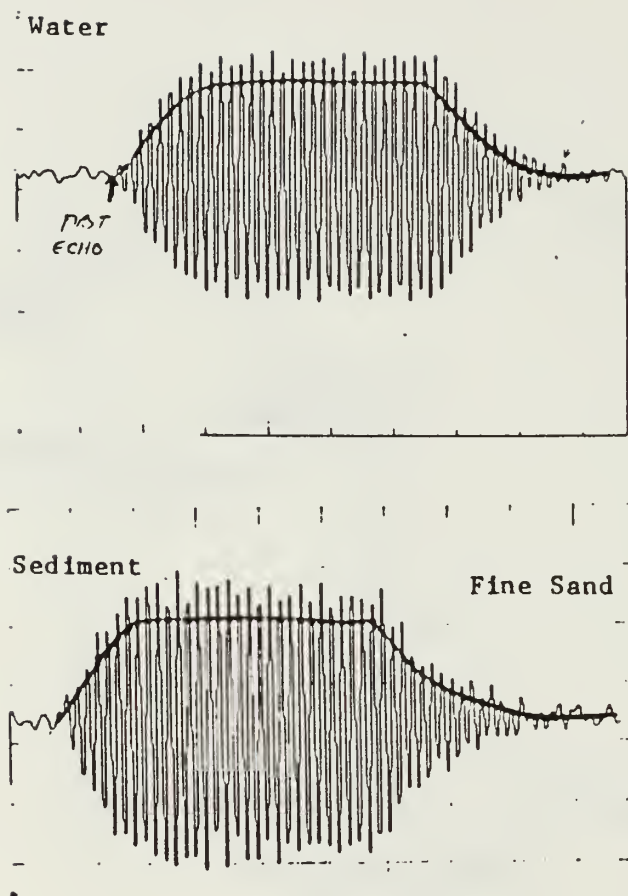


Figure 3.7 Water and Sediment Echo Envelopes.

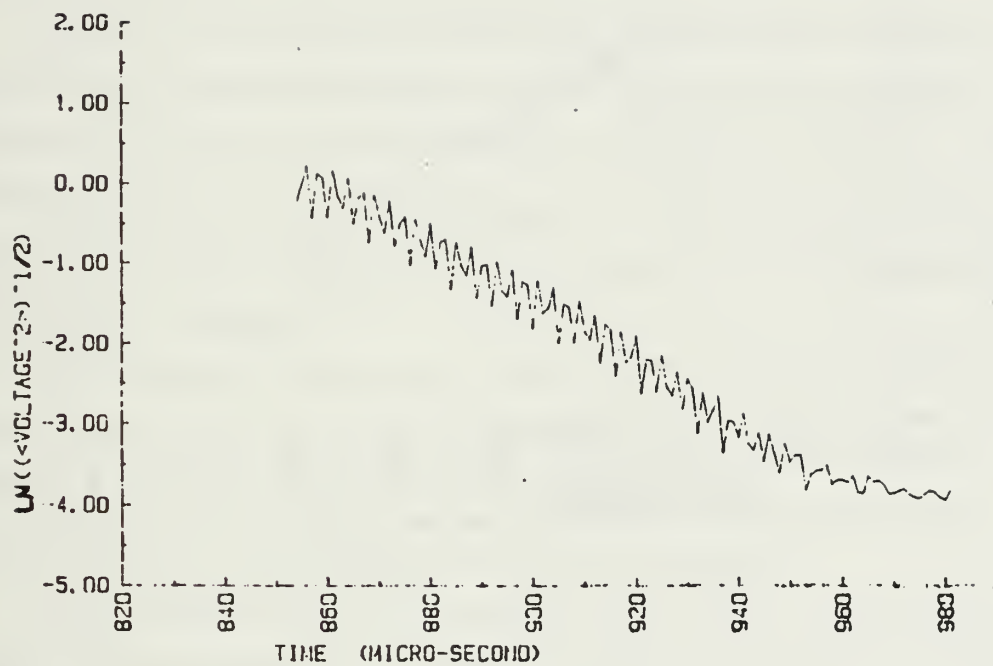


Figure 3.8 Averaged Squared Voltages in a Bin
(Tail Portion).

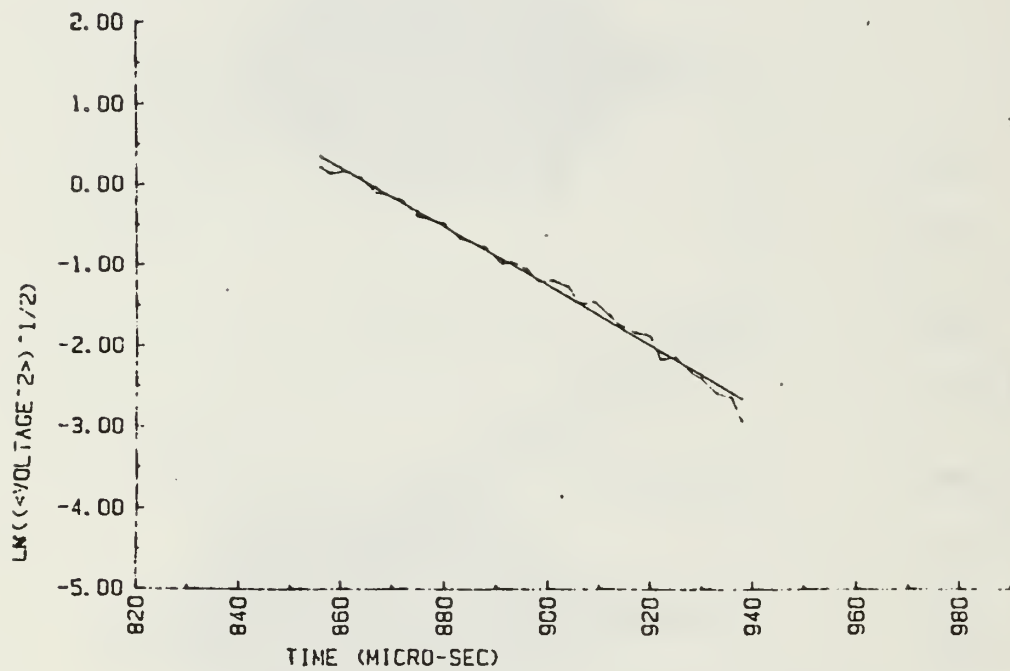


Figure 3.9 Averaged Squared Voltages of the Local Maxima.

IV. PRELIMINARY MEASUREMENTS

A. WATER

The expected density of room temperature water is 1.00 g/cm^3 (Lange, 1967). Measured volumes of the water, taken from the tanks, were periodically weighed and the observed density was $1.00 \pm 0.01 \text{ g/cm}^3$.

Speed of sound experiments for fresh water were performed as a check on the equipment and experimental techniques. LC10 hydrophones were used in these measurements both as transmitter and receivers. The LC10 is a small (0.97 cm diameter) cylinder with a receiving range of 0.1 to 120,000 Hz. The LC10 was designed to be omni-directional in a plane perpendicular to the axis of the cylinder with a tolerance of $\pm 1 \text{ dB}$ at 100 kHz. A directivity pattern for an LC10 (measured at 180 kHz) is shown on Figure 4.1.

This experiment involved the use of three LC10 hydrophones (Figure 4.2). One was used as the source. A second LC10 was placed 10 cm from the source and the third LC10 was moved along a line passing through the other two transducers. The travel time between the receivers was measured, and the data are summarized in Table 3 of Appendix B. A plot of distance versus time is in Figure 4.3.

The measured sound speed of water was $1453 \pm 20 \text{ m/s}$. As a check, the following equation (Kinsler, Frey, Coppens, Sanders, 1982) was used to calculate speed of sound for fresh water:

$$c = 1402.7 + 488t - 482t^2 + 135t^3$$

where $t = T/100$ and T is temperature in degrees Celsius. The measured temperature for the water was 16°C . The computed sound speed in water was 1467.90 m/s with an uncertainty of $\pm 0.01 \text{ m/s}$.

B. SEDIMENTS

1. Physical properties

Two types of sediment were sieved and sized by personnel of the Geology Department, University of California at Santa Cruz.

Monterey #30 Fine Sand = $300.0 \text{ }\mu\text{m}$

Aquarium #2 Aggregate = 5.3 mm

Bradshaw (1981) measured the water-saturated density ρ_{mix} and dry density ρ_1 of the fine sand,

$$\begin{aligned}\rho_{\text{mix}} &= 1.98 \pm 0.03 \text{ g/cm}^3 \\ \rho_{\text{dry}} &= 2.69 \pm 0.01 \text{ g/cm}^3\end{aligned}$$

Density and porosity measurements were performed in the laboratory for the aggregate. Ten separate measurements, yielded a density of $1.97 \pm 0.03 \text{ g/cm}^3$ for the water saturated sediment and a dry density ρ_1 of $2.64 \pm 0.05 \text{ g/cm}^3$. The porosity β of the aggregate was measured to be 0.59 ± 0.01 . The dry density was 2.64 g/cm^3 as computed from the following equation (Urick, 1979):

$$\begin{aligned}\rho_{\text{mix}} &= \beta\rho_1 + (1 - \beta)\rho_2 \\ \rho_{\text{mix}} &= 1.97 \text{ g/cm}^3 \\ \beta &= \text{Porosity} = 0.59 \\ \rho_1 &= \text{Density of individual grains} = 2.64 \text{ g/cm}^3 \\ \rho_2 &= \text{Density of Water} = 1.00 \text{ g/cm}^3\end{aligned}$$

The data are summarized in Table 2 of Appendix C.

2. Sound speed

Speed of sound for the sediment (aggregate) was performed as for water, except the transducer and two receivers were buried 10 cm below the surface of the sediment (Figure 4.4). The data are summarized in Table 4 of Appendix B. A plot of distance versus time is shown in Figure 4.5. The sound speed was linearly estimated (Figure 4.5) to be $1555 \pm 50 \text{ m/s}$ and measured to be $1583 \pm 84 \text{ m/s}$. Comparison between measured and estimated values is good.

C. TESTS PERFORMED ON TRANSDUCER

1. Beam pattern and beamwidth

(a.) In the far field, the radiation from a continuous-line source can be expressed as a product of an on-axis pressure $P_{\text{ax}}(r)$ which depends only on r and a term $H(\theta, \phi)$, which depends only on angle. The term that depends on the angle, called the directional factor, is normalized so that its maximum value is unity (Kinsler, Frey, Coppens, Sanders, 1982). The directions for which $H = 1$ determine the acoustical axes. In cases with high degrees of symmetry, the acoustic axis becomes a plane or a line. The variation of intensity level with angle is the beam pattern:

$$\begin{aligned}
b(\theta, \phi) &= 10 \text{ LOG } \{I(r, \theta, \phi) / I_{ax}(r)\} \\
&= 20 \text{ LOG } H(\theta, \phi) \\
&= 20 \text{ LOG } \{P(r, \theta, \phi) / P_{ax}(r)\}
\end{aligned}$$

Since the pressure amplitude (P) is proportional to the voltage amplitude (V):

$$\begin{aligned}
20 \text{ LOG } \{P(r, \theta, \phi) / P_{ax}(r)\} \\
= 20 \text{ LOG } \{V(r, \theta, \phi) / V_{ax}(r)\}
\end{aligned}$$

The term $P_{ax}(r)$ is the far-field pressure on the acoustic axis; the pressure along any other radial line is simply $P_{ax}(r)$ reduced by the factor $H(\theta, \phi)$.

The beam pattern measured for the F-41, is shown in Figure 4.6. Data were recorded in increments of 5°. These data are summarized in Table 1 of Appendix B.

(b.) No standard value of the ratio $I(\theta, \phi) / I_{ax}$ has been agreed on for measuring or calculating the angles θ and ϕ that mark the effective extremity of the major lobe. The particular value employed must be clearly stated when beamwidths are specified in this manner. The ratio used for this experiment was 0.5 (down 3 dB), so that:

$$\begin{aligned}
-3 \text{ dB} &= 20 \{ \text{LOG } P(r, \theta, \phi) / P_{ax} \} \\
-3 \text{ dB} &= 20 \{ \text{LOG } P(r, \theta, \phi) / P_{ax} \} \\
P / P_{ax} &= 0.7079
\end{aligned}$$

The beamwidth of a baffled circular piston source can be calculated from (8.36) and Table A6 of Kinsler, Frey, Coppens, and Sanders (1982) using

$$\begin{aligned}
1.7 &= ka \sin(\theta) \\
\lambda &= 0.83 \text{ cm} \\
a &= 4.4 \text{ cm (radius of the active face of the F-41) we have} \\
\theta &= 3.00^\circ
\end{aligned}$$

The half beamwidth for the F-41 was measured to be 10°. The difference between the measured and calculated beamwidth is probably because the F-41 is not a baffled transducer.

2. Near field

In the near field of a transmitter, the sound field is irregular and does not fall off smoothly with distance, as in the far field. The two regions are separated by a transition region. In the near field the wavefronts are nondivergent; in the far field the wavefronts are smooth and spherical (Urick, 1983).

Axial voltage for a baffled circular piston source exhibits interference effects in the near field. The extremes of voltage occur for values of r satisfying:

$$(1/2)(kr)\{\sqrt{1+(a/r)^2} - 1\} = m\pi / 2$$

maxima: m odd

minima: m even

where $m = 0, 1, 2, 3, \dots$. Solution of the above for values of r at the extremes yields

$$r_m/a = (1/m)(a/\lambda) - (m/4)(\lambda/a)$$

$$a = 4.4 \text{ cm}$$

$$\lambda = 0.833 \text{ cm}$$

The computed values of r at the extremes are

$$r_1 = 23.03 \text{ cm (maximum)}$$

$$r_2 = 11.20 \text{ cm (minimum)}$$

$$r_3 = 7.12 \text{ cm (maximum)}$$

For values of r less than r_1 , the axial voltage displays interference effects suggesting the complexity of the acoustic field near the face of the source. The distance r_1 serves as a convenient demarcation between the near field (near the source) and the far field (at far distances from the source).

Measurements were taken to determine the extent of the near field of the F-41. The F-41 was held fixed at one end of the tank, while a LC10 receiver was moved along the acoustic axis in uniform increments. The voltage readings were plotted as a function of inverse distance from 15 cm to 150 cm (Figure 4.7). In the far field the voltages display a decreasing behavior going asymptotically to a $1/r$ dependence. All reflection measurements were performed in the far field. A summary of these data are in Table 2 of Appendix B.

3. Pressure reflection coefficient

The pressure reflection coefficient at normal incidence were measured for both sediments and the results compared to those calculated from measured values of ρ and c . The reflection coefficient (R) is given by:

$$R = (\rho_W c_W - \rho_S c_S) / (\rho_W c_W + \rho_S c_S)$$

where

ρ_W = Density of Water

c_W = Sound Speed in Water

ρ_S = Density of Sediment

c_S = Sound Speed in Sediment

Model geometry for these experiments is shown in Figure 4.8.

The reflection coefficient for the fine sand was measured in the larger wooden tank. The sediment was kept smooth and horizontal for normal incidence. The F-41 was mounted at the surface of the water pointed vertically downward toward the sediment. The oscilloscope voltage V_2 readings of the received signal were recorded. The F-41 was then placed on the sediment bottom, pointed toward the water surface. The voltage reading V_1 of the received signal was recorded. The ratio of V_2 / V_1 is the reflection coefficient. The experiments were performed at three different water depths (40 cm, 35 cm, 30 cm) to ensure consistant observed values for R and to compare observed and computed values. A summary of the measured data is shown in Table 1 of Appendix C.

The density of the fine sand is $1.98 \pm 0.03 \text{ g/cm}^3$ and sound speed is 1600 m/s (Bradshaw, 1981), giving a reflection coefficient for normal incidence of 0.36 (Borchardt, 1985). Measured reflection coefficient is 0.36 ± 0.01 . Expected and measured reflection coefficients are in excellent agreement.

Reflection coefficient experiments on the aggregate were conducted in the steel-bound glass tanks. The aggregate was kept smooth and horizontal throughout the experiments. The values used in calculating the reflection coefficient for normal incidence for the aggregate were

$$\rho_W = 1.000 \text{ g/cm}^3 \quad \rho_S = 1.97 \text{ g/cm}^3$$

$$c_W = 1452.95 \text{ m/s} \quad c_S = 1550.00 \text{ m/s}$$

from which $R = 0.356$

These experiments were performed at three different depths (35 cm, 30 cm, 25 cm) to ensure consistency of the experimental procedure. A summary of these results is shown in Table 1 of Appendix C.

The measured reflection coefficient for the aggregate is 0.26 ± 0.01 . The computed and measured values for reflection coefficient are not in good agreement. In this case the Raleigh model (two fluid) does not apply (Anderson and Liebermann, 1968).

D. SUMMARY OF PRELIMINARY MEASUREMENTS

1. Test tank criteria

Trial runs in the wooden tank and in the glass-bound tank, showed that a longer pulse length would be required to ensure the signal emitted by the transducer reaches equilibrium and that the transmitted signal would not interfere with the receive signal. The wooden tray arrangement suspended in the anechoic tank provided the necessary water depth and sediment thickness required by the longer pulse.

2. Sediment criteria

It was decided not to use the fine sand as the echo showed minimal traces of volume backscatter. The aggregate was believed to have greater volume backscatter.

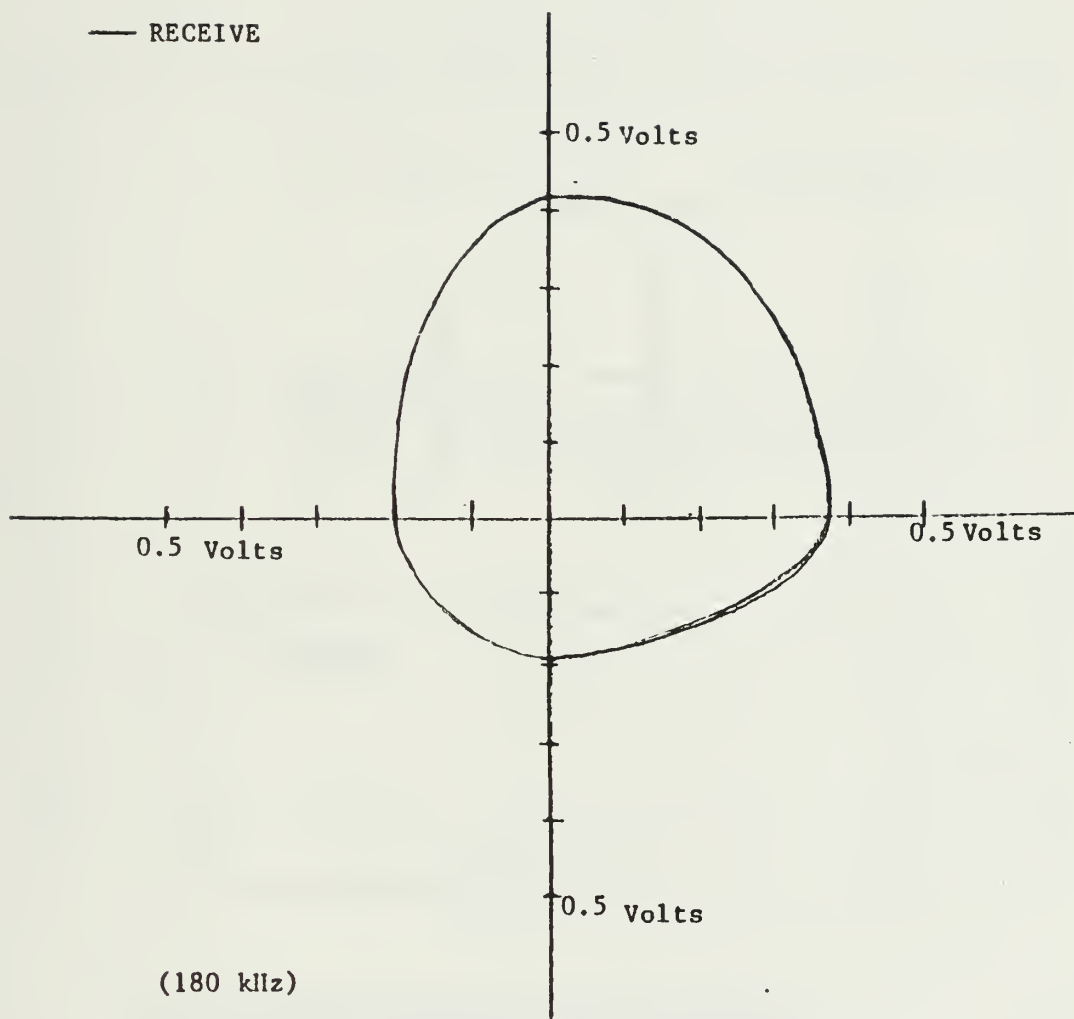


Figure 4.1 Directivity Pattern for A503 LC10 Receiver.

DRAWING NOT TO SCALE

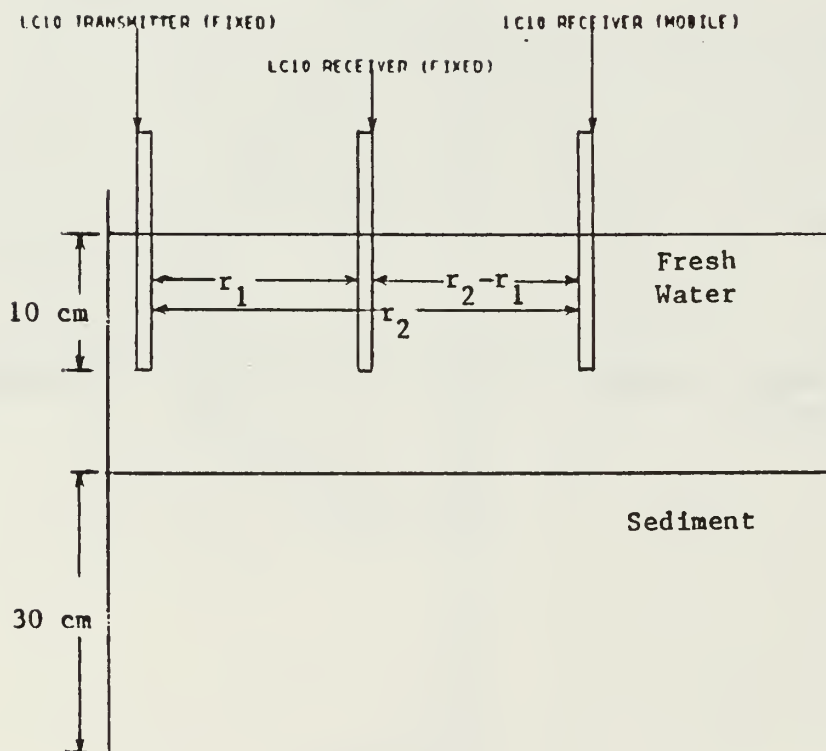


Figure 4.2 Model Geometry for Speed of Sound in Water.

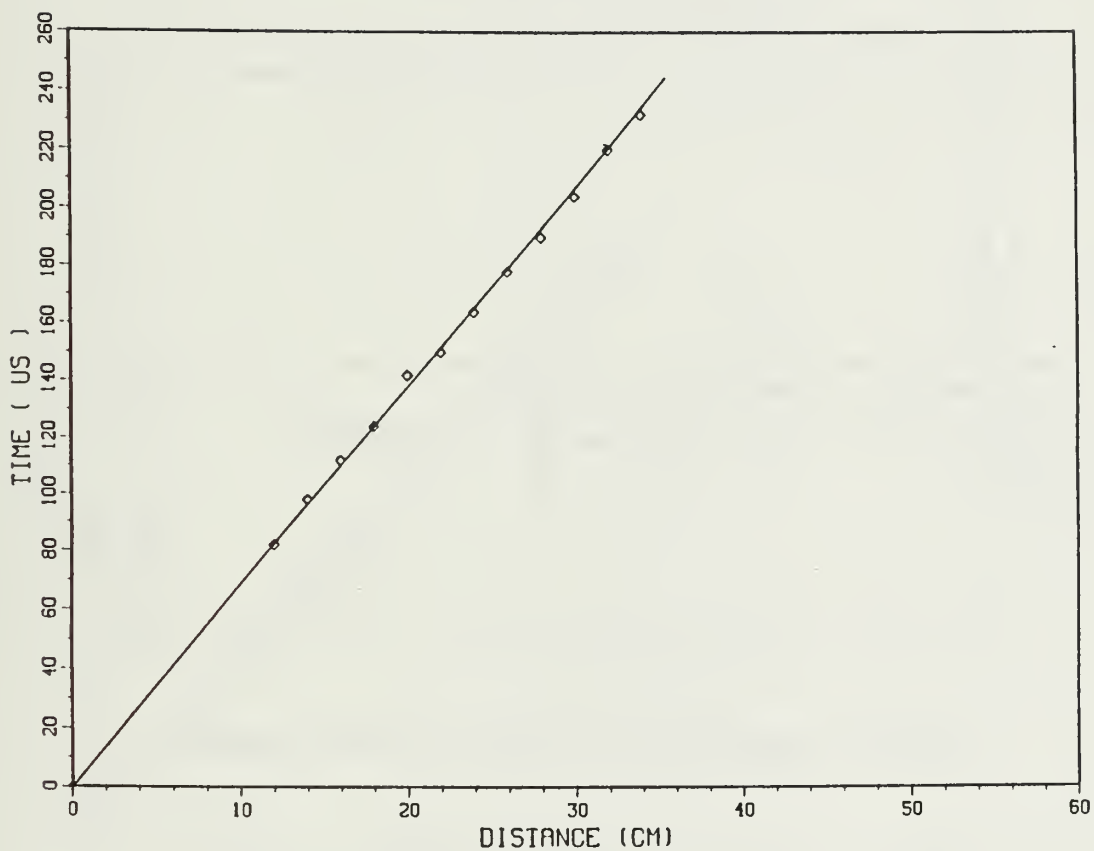


Figure 4.3 Distance versus Time (Water).

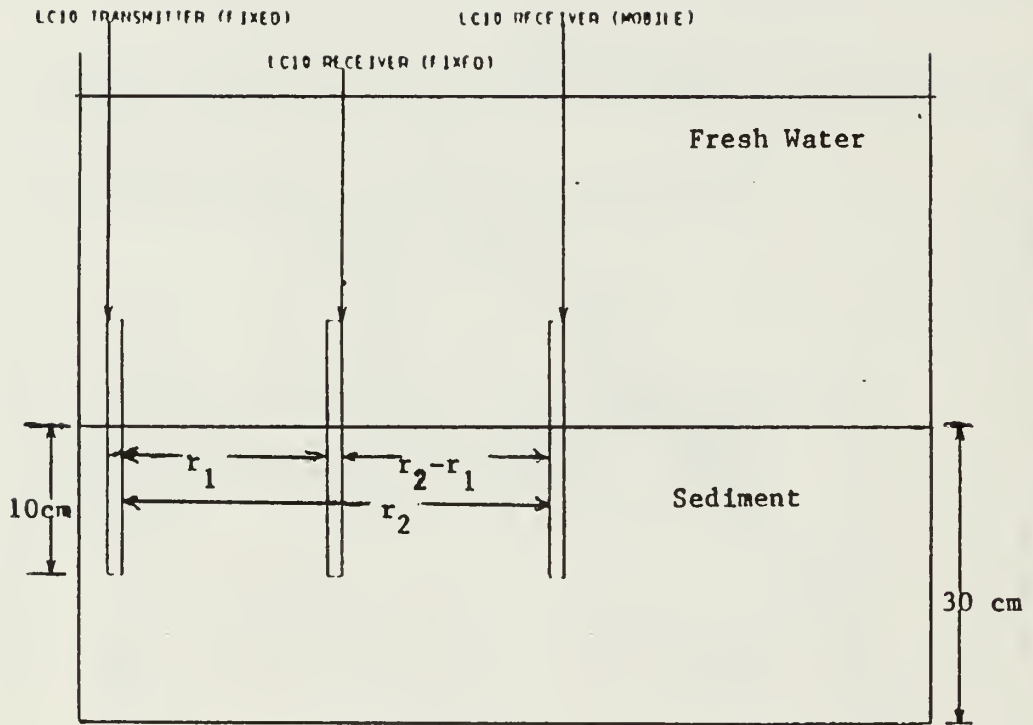


Figure 4.4 Model Geometry for Speed of Sound in Aggregate.

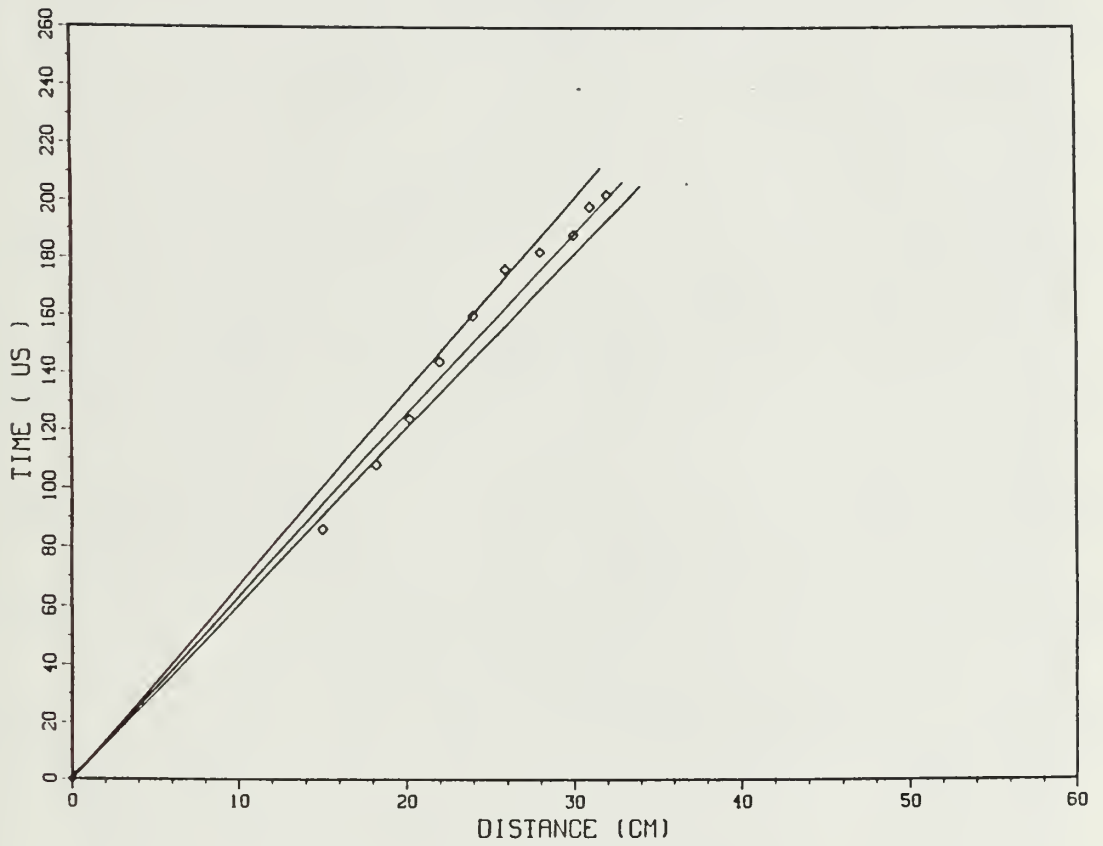


Figure 4.5 Distance versus Time (Aggregate).

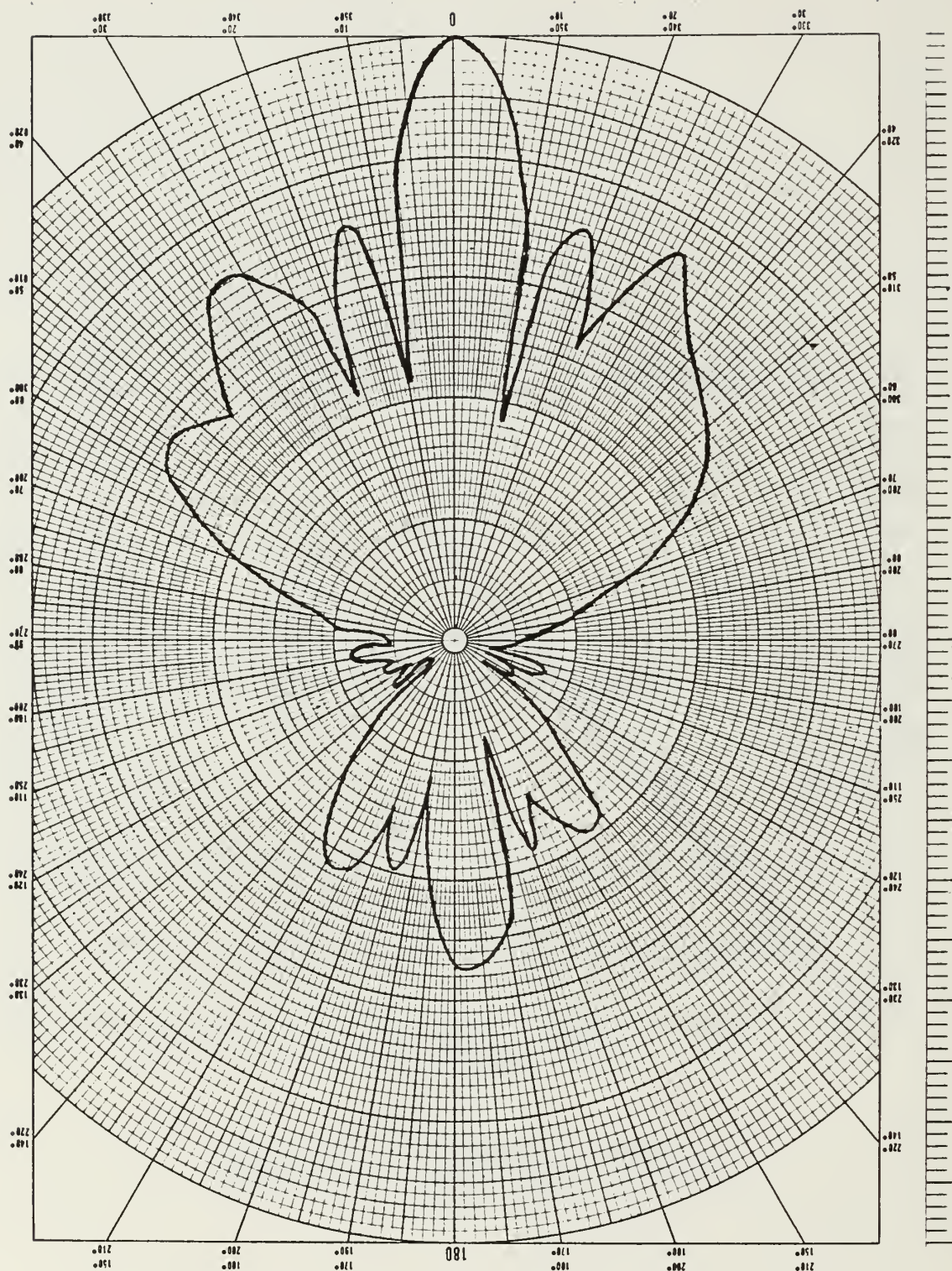


Figure 4.6 Beam Pattern for F-41 Transducer
(Units in dB).

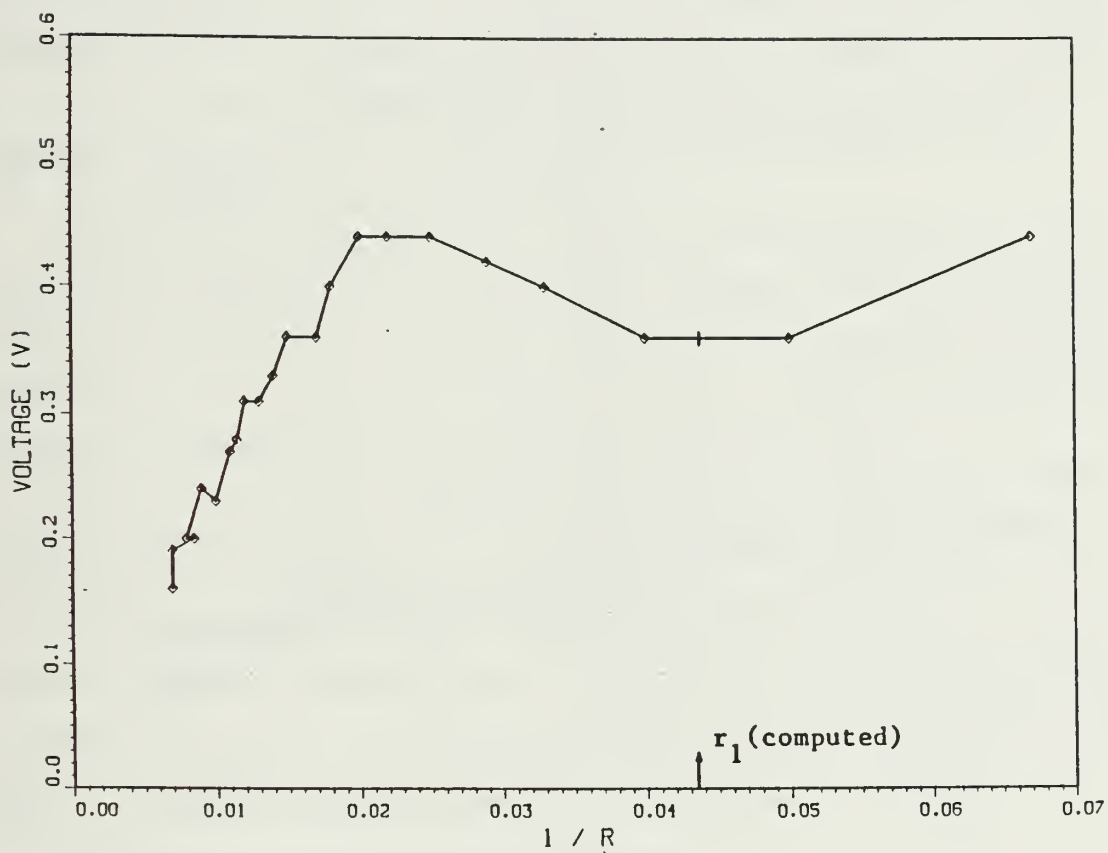


Figure 4.7 Extent of the Near Field.

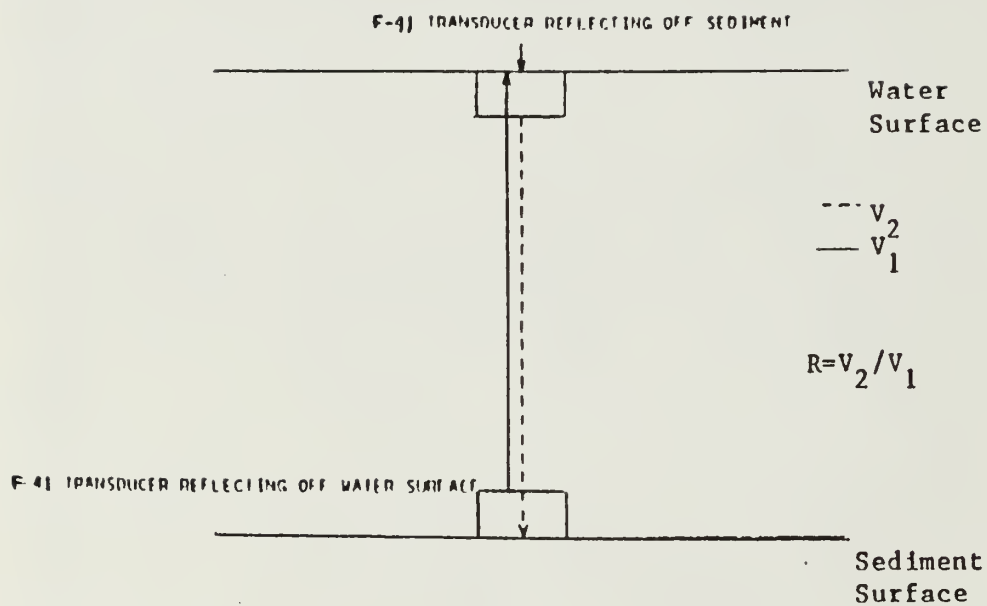


Figure 4.8 Model Geometry for Pressure Reflection Coefficient.

V. RESULTS

The data sets for reflection from the water/air interface are DATA3, DATA4 and DATA6 through DATA11, Appendix D. The distance between the F-41 and the water/air interface was kept constant at 55 cm for each set. These echoes were sampled from 840 μ s to 983 μ s after the beginning of the echo, and the sets are consistent up to 940 μ s. Interference, of an unknown source, began to occur at 940 μ s. The data, truncated at 940 μ s, shows a linear exponential decay. See Table 1, Appendix D for results. The mean value for the decay constant for the water/air reflection data is $(-3.84 \pm 0.14) \times 10^{-2} \mu\text{s}^{-1}$.

The data sets for reflection from the aggregate are DATA1, DATA2, DATA5, DATA12, DATA13 and DATA14, Appendix D. The distance between the F-41 and sediment was 55 cm, the same as for water. These echoes were sampled at the same time interval as for the echoes from the water/air interface. The unknown interference was again evident after 940 μ s and the data were truncated at 940 μ s.

There was considerable evidence of inhomogenities in the sediment. For a few locations, the decay was regular and exponential in nature, although with a decay constant different from that for the water/air interface.

For the sets DATA15, DATA16 and DATA17, the F-41 was set at 30 cm, 50 cm and 70 cm, respectively, above the sediment surface. The F-41 was moved horizontally to ensound different areas of the sediment. For these selected samples, the mean value for the decay constant was $(-3.08 \pm 0.69) \times 10^{-2} \mu\text{s}^{-1}$. See Table 2 Appendix D for results.

The following general observation can be made:

Slight variations in source positioning (vertically and horizontally) led to vastly different results.

VI. CONCLUSIONS AND RECOMMENDATIONS

At this point, measurement of volume reverberation within sediments is not predictable because of the inconsistencies of the data available. The study of the effects of source position on the results for reflection from the water/air interface did not uncover any major failures. In general, there was excellent consistency among the measurements made on the water/air interface. Minor variations of source positioning had a pronounced effect on the echo reflection from the sediment.

Future experimentation should include further variation of the position of the source (horizontal and vertical) for water measurements to determine whether the experimental system operates consistently before performing any additional measurements on sediment. It is recommended to use finer sediments or glass beads of uniform radius to test the importance of inhomogeneities in the sediment. Further, it is recommended that the following equipment modifications be made:

- (a) The carriage for holding the transducer should be re-designed to allow precise horizontal and vertical movement of the transducer. These movements should be recorded so that data sets could be duplicated if needed.
- (b) Fabricate a smaller tray (e.g., 80 cm x 80 cm x 60 cm) using a sediment depth of 30 to 40 cm.

Continued use of the computer programs written for this project on the HP-86 is highly recommended.

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APPENDIX A

COMPUTER PROGRAMS

THEISE I

DATA ACQUISITION PROGRAM

```

2000 DIM D(1101),T(1101),S(1101)
2020 INTEGER N,I
2040 LET N=1
2080 DISP "IS THIS YOUR FIRST DATA SET OUT OF THE 100 DATA SET?"
2100 DISP "PRESS 0 IF YES ; PRESS 1 IF NO"
2120 INPUT ANS
2140 IF ANS=1 THEN GOSUB READ_DATA
2240 DIM I$(5),D$(20000),N$(40)
2260 CONTROL 10,3 : 15
2280 CONTROL 10,4 : 58
2300 CONTROL 10,2 : 1
2320 DISP "PRESS 3091 BUTTON"
2340 ENTER 10 : I$
2360 ENTER 10 : D$
2380 ENTER 10 : N$
2400 HO=VAL (N$(16,20))
2420 V1=(VAL (N$(21,25))-5)*10^(VAL (N$(26,30))-12)
2440 H1=(VAL (N$(31,35))-5)*10^(VAL (N$(36,40))-12)
2460 J=1
2480 K=5
2500 PRINT "N=",N
2520 FOR I=0 TO 1200
2525 IF I<1000 OR I>1100 THEN 2780
2540 D(I)=VAL (D$(J,K))*V1
2560 T(I)=(1-HO)*H1
2580 D(I)=D(I)^2
2600 IF N=1 THEN GOTO 2640
2620 S(I)=((N-1)*S(I)+D(I))/N
2640 IF N=1 THEN S(I)=D(I)
2660 IF I=1000 THEN 2760 ELSE 2680
2680 IF I=1010 THEN 2760 ELSE 2700
2700 IF I=1040 THEN 2760 ELSE 2720
2720 IF I=1050 THEN 2760 ELSE 2740
2740 IF I=1100 THEN 2760 ELSE 2780
2760 DISP T(I); "SEC " ; D(I); "VOLT " ; S(I)
2770 PRINT T(I); "SEC " ; D(I); "VOLT " ; S(I)
2780 J=J+5
2800 K=K+5
2820 NEXT I
2840 N=N+1
2860 IF N=101 THEN GOTO 2761
2900 DISP "DO YOU HAVE ANOTHER SET OF DATA TO COLLECT?"
2920 DISP "PRESS 0 IF YES ; PRESS 1 IF NO"
2940 INPUT YES
2960 IF YES=0 THEN GOTO 2240
2961 IF ANS=1 THEN 2780
2970 CREATE "DATA17",200.8
2971 CREATE "COUNT17",1.8
2972 CREATE "TIME17",200.8
2780 GOSUB WRITE_DISK
3000 END

```


THEISE I Continued

```

3500 WRITE DISK:
3510 PURGE "DATA17"
3520 CREATE "DATA17",200,8
3540 ASSIGN# 1 TO "DATA17"
3550 PURGE "COUNT17"
3560 CREATE "COUNT17",1,8
3580 ASSIGN# 2 TO "COUNT17"
3590 PURGE "TIME17"
3600 CREATE "TIME17",200,8
3620 ASSIGN# 3 TO "TIME17"
3640 PRINT# 2 : N
3660 FOR I=1000 TO 1100
3680 PRINT# 3 : T(I)
3700 PRINT# 1 : S(I)
3720 NEXT I
3740 ASSIGN# 1 TO *
3760 ASSIGN# 2 TO *
3780 ASSIGN# 3 TO *
3800 RETURN
4000 READ DATA:
4020 ASSIGN# 2 TO "COUNT17"
4040 ASSIGN# 1 TO "DATA17"
4060 READ# 2 : N
4061 PRINT N
4080 FOR I=1000 TO 1100
4100 READ# 1 : S(I)
4120 IF I=1000 THEN 4220 ELSE 4140
4140 IF I=1010 THEN 4220 ELSE 4160
4160 IF I=1040 THEN 4220 ELSE 4180
4180 IF I=1050 THEN 4220 ELSE 4200
4200 IF I=1100 THEN 4220 ELSE 4240
4220 PRINT S(I)
4240 NEXT I
4260 ASSIGN# 1 TO *
4280 ASSIGN# 2 TO *
4380 RETURN

```

MAXI

LOCAL MAXIMUM DETERMINATION

```
1000 ASSIGN# 1 TO "DATA"
1020 ASSIGN# 3 TO "TIME"
1040 CREATE "NUMBER",1,8
1060 ASSIGN# 4 TO "NUMBER"
1080 CREATE "TIME_MAX",100,8
1100 ASSIGN# 5 TO "TIME_MAX"
1120 CREATE "MAXIMUM_S",100,8
1140 ASSIGN# 6 TO "MAXIMUM_S"
1160 DIM S(1001),T(1001),TIM(100),MAXS(100)
1180 INTEGER I,J
1200 FOR I=822 TO 982
1220 READ# 3 : T(I)
1240 READ# 1 : S(I)
1260 NEXT I
1280 LET J=0
1300 IF S(822) >= S(823) THEN 1320 ELSE 1500
1320 TIM(J)=T(822)
1340 MAXS(J)=SOR (S(822))
1360 PRINT# 5 : TIM(J)
1380 PRINT# 6 : MAXS(J)
1400 PRINT "J=";J;"T=";TIM(J);" " " :MAXS(J)
1420 ! PRINT TIM(J)
1440 ! PRINT MAXS(J)
1460 J=J+1
1480 !
1500 FOR I=823 TO 982
1520 IF S(I) >= S(I-1) AND S(I) >= S(I+1) THEN 1540 ELSE 1720
1540 TIM(J)=T(I)
1560 MAXS(J)=SOR (S(I))
1580 !
1600 PRINT "J=";J;"T=";TIM(J);" " " :MAXS(J)
1620 ! PRINT TIM(J)
1640 ! PRINT MAXS(J)
1660 PRINT# 5 : TIM(J)
1680 PRINT# 6 : MAXS(J)
1700 J=J+1
1720 NEXT I
1740 J=J-1
1760 PRINT# 4 : J
1780 ASSIGN# 4 TO *
1800 ASSIGN# 5 TO *
1820 ASSIGN# 6 TO *
1840 ASSIGN# 1 TO *
1880 ASSIGN# 3 TO *
1900 END
```

PLOT 1

LOCAL MAXIMUM PLOT

```
1000 CLEAR
1020 GCLEAR:
1040 FRAME
1060 LOCATE 20,135,20,95
1080 CSIZE 4
1100 MOVE 40,10
1120 LABEL "TIME (MICRO-SEC)"
1140 PEN UP
1160 MOVE 8,30
1180 DEG
1200 LDIR 90
1220 LABEL "LN((VOLTAGE^2)^(1/2))"
1240 PEN UP
1260 DISP "ENTER THE XMIN OF SCALE"
1280 INPUT XMIN
1300 DISP "ENTER XMAX OF SCALE"
1320 INPUT XMAX
1340 DISP "ENTER THE YMIN OF SCALE"
1360 INPUT YMIN
1380 DISP "ENTER THE YMAX OF SCALE "
1400 INPUT YMAX
1420 SCALE XMIN,XMAX,YMIN,YMAX
1440 FXD 0,2
1460 DISP "ENTER THE X-TICKING SPACE"
1480 INPUT XT
1500 DISP "ENTER THE Y-TICKING SPACE"
1520 INPUT YT
1540 DISP "ENTER THE X INTERSECTION"
1560 INPUT XI
1580 DISP "ENTER THE Y INTER SECTION"
1600 INPUT YI
1620 DISP "ENTER THE X-MAJOR COUNT"
1640 INPUT XMC
1660 DISP "ENTER THE Y-MAJOR COUNT"
1680 INPUT YMC
1700 LAXES XT,YT,XI,YI,XMC,YMC
1710 GRAPH
1720 PEN 1
1740 DIM TIM(100),MAXS(100)
1741 DIM TIMEMAX$(20),MAXIMUM$(20)
1742 DISP "WHAT IS YOUR FILE NAME FOR TIMEMAX$ ?"
1744 INPUT TIMEMAX$
1746 DISP "WHAT IS YOUR FILE NAME FOR MAXIMUM$ ?"
1748 INPUT MAXIMUM$
1749 PRINT "THE DATA FILES ARE",TIMEMAX$,"AND",MAXIMUM$
1750 DISP "WHAT IS THE HIGHEST ORDER OF ARRAY NUMBER?"
1752 INPUT JK
1760 ASSIGN# 5 TO TIMEMAX$
1780 ASSIGN# 6 TO MAXIMUM$
```

PLOT 1 Continued

```

1781 DISP "PRESS Q IF THE FIRST LOCAL MAXIMUM IS BEING SAVED ?"
1782 INPUT OK
1790 FOR I=0 TO JF
1800 READ# 5 : TIM(I)
1810 TIM(I)=TIM(I)*1000000
1820 READ# 6 : MAXS(I)
1821 MAXS(I)=LOG (MAXS(I))
1823 NEXT I
1825 K=JF+1
1826 IF OK=0 THEN GOTO 1835
1828 FOR I=1 TO JF
1831 TIM(I-1)=TIM(I)
1832 MAXS(I-1)=MAXS(I)
1833 NEXT I
1834 K=JF
1835 ! DISP "WHICH CHARACTER YOU PREFER TO USING IN PLOTTING THE DATA?"
1837 ! INPUT C#
1839 MOVE TIM(0),MAXS(0)
1840 FOR I=0 TO K-1
1920 DRAW TIM(I),MAXS(I)
1930 ! LABEL C#
1940 NEXT I
1960 PEN UP
1962 GOSUB LEASTSQ
1980 ASSIGN# 5 TO *
2000 ASSIGN# 6 TO *
2020 END
3000 LEASTSQ:
3040 REAL Y,XY,X1,X2,TAVE,YAVE,VARX,VARY,COVXY
3060 LET Y=0
3080 ! Y IS THE SUMMATION OF Y(I) VALUE
3100 LET XY=0
3120 ! XY IS THE SUMMATION OF X(I)*Y(I)
3140 LET X1=0
3160 ! X1 IS THE SUMMATION OF X(I)
3180 LET X2=0
3200 ! X2 IS THE SUMMATION OF X(I)^2
3220 FOR I=0 TO K-1
3240 Y=Y+MAXS(I)
3260 XY=XY+TIM(I)*MAXS(I)
3280 X1=X1+TIM(I)
3300 X2=X2+TIM(I)^2
3320 NEXT I
3340 B=(X2*Y-X1*XY)/(K*X2-X1^2)
3350 !
3351 !
3352 ! A IS THE SLOPE OF THE FITTED STRAIGHT LIGHT
3360 A=(K*XY-X1*Y)/(K*X2-X1^2)
3370 !
3371 !
3372 ! B IS THE INTERCEPT TO Y AXIS
3380 PRINT "THE SLOPE A=";A
3400 PRINT "THE Y-INTERCEPT B=";B
3420 YAVE=(MAXS(0)+MAXS(K-1))/2
3440 TAVE=(TIM(0)+TIM(K-1))/2

```

PLOT 1 Continued

```

3460 COVXY=0
3461 !
3480 !      COVXY IS THE COVARIANCE OF  TIME AND VOLTAGE (LN)
3481 !
3500 VARX=0
3520 !      VARX IS THE VARIANCE OF TIME VARIABLE
3521 !
3540 VARY=0
3560 !      VARY IS THE VARIANCE OF VOLTAGE(LN) VARIABLE
3561 !
3562 DIM YL(100)
3580 FOR I=0 TO K-1
3600 !
3620 COVXY=COVXY+(TIM(I)-TAVE)*(MAXS(I)-YAVE)
3640 !
3660 VARX=VARX+(TIM(I)-TAVE)^2
3680 !
3700 VARY=VARY+(MAXS(I)-YAVE)^2
3720 !
3740 YL(I)=A*TIM(I)+B
3760 !      YL IS THE VALUE FITTED ON THE STRAIGHT LINE
3761 !
3780 NEXT I
3800 PEN 2
3820 MOVE TIM(0),YL(0)
3840 FOR I=0 TO K-1
3860 DRAW TIM(I),YL(I)
3880 NEXT I
3900 CORCOE=COVXY/SQR (VARX*VARY)
3920 !      CORCOE IS THE CORRELATION COEFFICIENT
3940 !
3960 PRINT "CORRELATION COEFFICIENT IS ";CORCOE
3980 RETURN

```

PLOT

AVERAGED POINT PLOT

```

1000 CLEAR
1020 GCLEAR
1040 FRAME
1060 LOCATE 20,135,20,95
1080 CSIZE 4
1100 MOVE 40,10
1120 LABEL "TIME (MICRO-SECOND) "
1140 PEN UP
1160 MOVE 8,30
1180 DEG
1200 LDIR 90
1220 LABEL "LN((VOLTAGE**2)**1/2)"
1240 PEN UP
1241 DISP "DO YOU WANT TO USE THE DEFAULT SCALE SET UP ? YES = 0"
1242 INPUT BULL
1243 IF BULL=0 THEN 1244 ELSE 1260
1244 SCALE 820,970,-5,2
1245 FXD 0,2
1246 LAXES 10,.5,820,-5,2,2
1250 IF BULL=0 THEN 1460
1260 DISP "ENTER THE XMIN OF SCALE"
1280 INPUT XMIN
1300 DISP "ENTER XMAX OF SCALE"
1320 INPUT XMAX
1340 DISP "ENTER THE YMIN OF SCALE"
1360 INPUT YMIN
1380 DISP "ENTER THE YMAX OF SCALE "
1400 INPUT YMAX
1420 SCALE XMIN,XMAX,YMIN,YMAX
1440 FXD 0,2
1460 DISP "ENTER THE X-TICKING SPACE"
1480 INPUT XT
1500 DISP "ENTER THE Y-TICKING SPACE"
1520 INPUT YT
1540 DISP "ENTER THE X INTERSECTION"
1560 INPUT XI
1580 DISP "ENTER THE Y INTER SECTION"
1600 INPUT YI
1620 DISP "ENTER THE X-MAJOR COUNT"
1640 INPUT XMC
1660 DISP "ENTER THE Y-MAJOR COUNT"
1680 INPUT YMC
1700 LAXES XT,YT,XI,YI,XMC,YMC
1710 GRAPH
1720 PEN 1
1730 DIM VDATA$(20),TTIME$(20)
1731 DISP "INPUT THE DATA# FILE NAME "
1732 INPUT VDATA$
1733 DISP "INPUT THE TIME# FILE NAME "
1734 INPUT TTIME$
1740 DIM T(1001),S(1001)
1760 ASSIGN# 1 TO VDATA$
1780 ASSIGN# 3 TO TTIME$

```

PLOT Continued

```
1782  DISF "ENTER THE STARTING DATA COLLECTING TIME"
1784  INFUT START
1786  DISF "ENTER THE ENDING DATA COLLECTING TIME"
1788  INFUT ENDT
1790  FOR I=START TO ENDT
1800  READ# 1 : S(I)
1810  S(I)=SOR (S(I))
1820  READ# 3 : T(I)
1825  NEXT I
1830  MOVE T(START)*1000000,LOG (S(START))
1840  FOR I=START TO ENDT
1860  MAXS=LOG (S(I))
1880  X=T(I)*1000000
1900  Y=MAXS
1920  DRAW X,Y
1940  NEXT I
1950  PEN UP
1960  ASSIGN# 1 TO *
1980  ASSIGN# 3 TO *
2000  END
```


APPENDIX B

PRELIMINARY TESTS

TABLE 1
BEAM PATTERN

FREQUENCY = 180 kHz

DIRECTION (DEG.)	VOLTAGE (mV)	dB
000	300.2	0.00
005	193.0	-3.84
010	46.65	-16.17
012.5	7.78	-31.72
015	46.25	-16.24
017.5	54.05	-14.89
020	39.05	-17.72
022.5	18.55	-24.18
025	29.50	-20.15
030	63.80	-13.45
035	42.75	-16.90
040	28.85	-20.34
045	24.00	-21.94
050	20.05	-23.50
055	17.78	-24.50
060	13.25	-27.10
065	8.58	-30.90
070	5.53	-34.70
075	3.28	-39.20
080	2.75	-40.80
085	1.80	-44.40
090	1.70	-44.90
095	1.50	-46.00
100	0.98	-49.70

Table 1 continued

DIRECTION (DEG.)	VOLTAGE (mV)	dB
105	1.30	-47.30
110	2.35	-42.10
115	1.33	-47.10
120	1.78	-44.50
125	1.33	-47.10
130	2.45	-41.80
135	3.53	-38.60
140	8.33	-31.10
145	9.28	-30.20
150	7.23	-32.40
155	4.78	-36.00
160	8.03	-31.40
165	2.43	-41.80
170	14.05	-26.60
175	19.40	-23.80
180	21.90	-22.70
185	11.05	-28.68
190	3.53	-38.59
195	9.40	-30.09
200	5.15	-35.31
205	10.78	-28.90
210	11.15	-28.60
215	7.60	-31.93
220	2.63	-41.15
225	2.43	-41.84
230	1.23	-47.75
235	1.95	-43.75
240	1.53	-45.85
245	1.90	-43.97
250	1.80	-44.44

Table 1 continued

DIRECTION (DEG.)	VOLTAGE (mV)	dB
255	1.98	-43.61
260	2.65	-41.08
265	1.75	-44.69
270	1.80	-44.44
275	3.00	-40.00
280	3.38	-38.97
285	5.23	-35.18
290	9.03	-30.43
295	14.30	-26.44
300	23.10	-22.27
305	26.40	-21.12
310	22.70	-22.43
315	19.10	-23.93
320	33.10	-19.15
325	53.60	-14.96
330	50.55	-19.55
335	31.60	-28.96
337.5	10.70	-15.47
340	25.25	-21.50
345	54.00	-14.89
350	11.23	-28.54
355	130.00	-7.23
360	300.20	0.00

TABLE 2

NEAR FIELD

DISTANCE (cm)	VOLTAGE (V)
15.0	0.44
20.0	0.36
25.0	0.36
30.0	0.40
35.0	0.42
40.0	0.44
45.0	0.44
50.0	0.44
55.0	0.40
60.0	0.36
65.0	0.36
70.0	0.33
75.0	0.31
80.0	0.31
85.0	0.28
90.0	0.27
100.0	0.23
110.0	0.24
120.0	0.20
130.0	0.20
140.0	0.19
150.0	0.16

TABLE 3
SPEED OF SOUND IN WATER

DISTANCE (cm) ($r_2 - r_1$)	TIME (μ s)	Amplitude (mV) (FIXED) (MOBILE)		SOUND SPEED (m/s)
12.0	82	119.1	145.3	1463.4
14.0	98	"	129.1	1428.6
16.0	112	"	53.4	1428.5
18.0	124	"	58.0	1451.6
20.0	142	"	55.9	1408.5
22.0	150	"	85.1	1466.7
24.0	164	"	91.1	1463.4
26.0	178	"	95.7	1460.6
28.0	190	"	78.1	1473.6
30.0	204	"	82.2	1470.6
32.0	270	"	82.3	1454.5
34.0	232	"	106.0	1465.5

$$\bar{c} = 1453 \text{ m/s}$$

$$\sigma = 20 \text{ m/s}$$

TABLE 4
SPEED OF SOUND IN AGGREGATE

DISTANCE (cm) ($r_2 - r_1$)	TIME (μ s)	AMPLITUDE (mv) (Fixed) (MOBILE)		SOUND SPEED (m/s)
15.0	86	29.05	16.05	1744
18.2	108	"	19.55	1685
20.2	124	"	17.40	1629
22.0	144	"	12.00	1528
24.0	160	"	12.00	1500
25.9	176	"	14.25	1472
28.0	182	"	10.65	1538
29.8	188	"	10.55	1585
31.0	198	"	9.10	1566
32.0	202	"	9.05	1584

$$\bar{c} = 1583 \text{ m/s}$$

$$\sigma = 84 \text{ m/s}$$

APPENDIX C

REFLECTION COEFFICIENT AND DENSITY MEASUREMENTS

TABLE 1

NORMAL PRESSURE REFLECTION COEFFICIENT FOR FINE SAND

WATER DEPTH (cm)	V ₁ (mV)	V ₂ (mV)	R
30	4.18	1.44	0.35
35	6.83	2.40	0.35
40	4.72	1.85	0.38

NORMAL PRESSURE REFLECTION COEFFICIENT FOR AGGREGATE

WATER DEPTH (cm)	V ₁ (mV)	V ₂ (mV)	R
25	786.0	214.0	0.27
30	752.0	210.0	0.28
35	836.0	216.0	0.26

TABLE 2

DENSITY MEASUREMENTS IN AGGREGATE

OBSERVATIONS	MASS OF DRY SEDIMENT (g)	MASS OF SEDIMENT/ WATER MIXTURE (g)	VOLUME OF SEDIMENT TO WATER (ml)	MEASURED DENSITY OF MIXTURE (g/cm ³)
1	158.85	198.60	59	1.99
2	154.40	196.00	59	1.96
3	154.05	194.20	59	1.94
4	158.35	202.66	59	2.03
5	156.05	195.35	60	1.95
6	155.95	196.30	59	1.96
7	153.25	193.90	60	1.94
8	153.85	195.60	58	1.96
9	157.45	198.20	58	1.98
10	156.45	196.80	59	1.97

$$\bar{\rho}_{\text{mix}} = 1.97 \text{ g/cm}^3$$

$$\sigma = 0.03 \text{ g/cm}^3$$

$$\rho_{\text{dry}} = 2.64 \text{ g/cm}^3 \text{ (computed)}$$

Average Porosity of Sediment = 59%

APPENDIX D

RESULTS

TABLE 1
WATER/AIR REFLECTION

FREQUENCY: 185kHz

DATA SET	SAMPLE TIME (μs)	NUMBER OF SAMPLES IN DATA SET	SLOPE ($\times 10^{-2}$)	CORRELATION COEFFICIENT
DATA3	840-983	50	-3.7566	-0.9894
DATA4	" "	25	-3.7861	-0.9967
DATA6	" "	100	-3.6911	-0.9728
DATA7	" "	5	-4.0184	-0.9985
DATA8	" "	10	-3.9628	-0.9876
DATA9	" "	25	-3.9688	-0.9920
DATA10	" "	50	-3.5874	-0.9801
DATA11	" "	50	-3.9209	-0.9986

MEAN SLOPE = $-3.84 \times 10^{-2} \mu s^{-1}$

$\sigma = 0.14 \times 10^{-2} \mu s^{-1}$

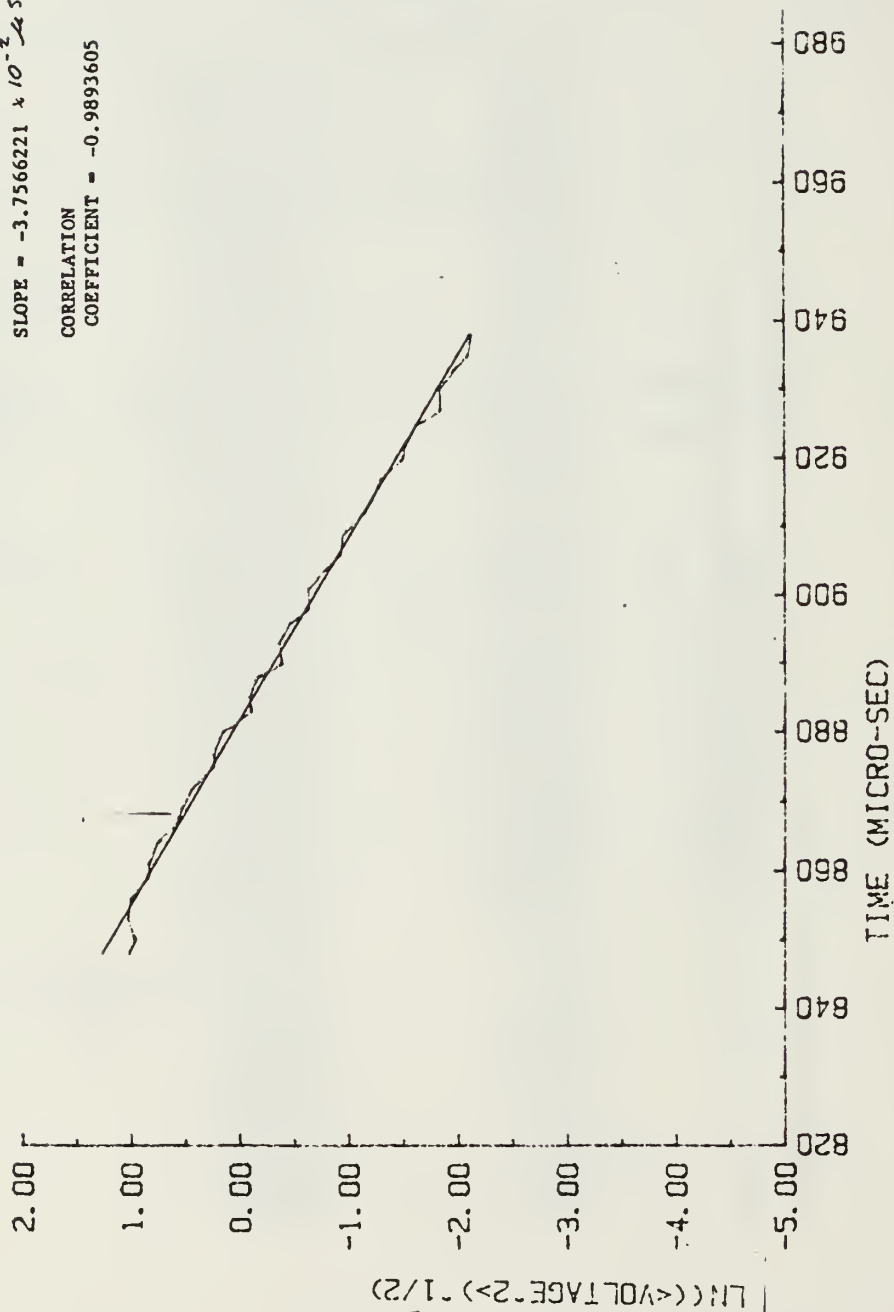
DATA3

LOCAL MAXIMA

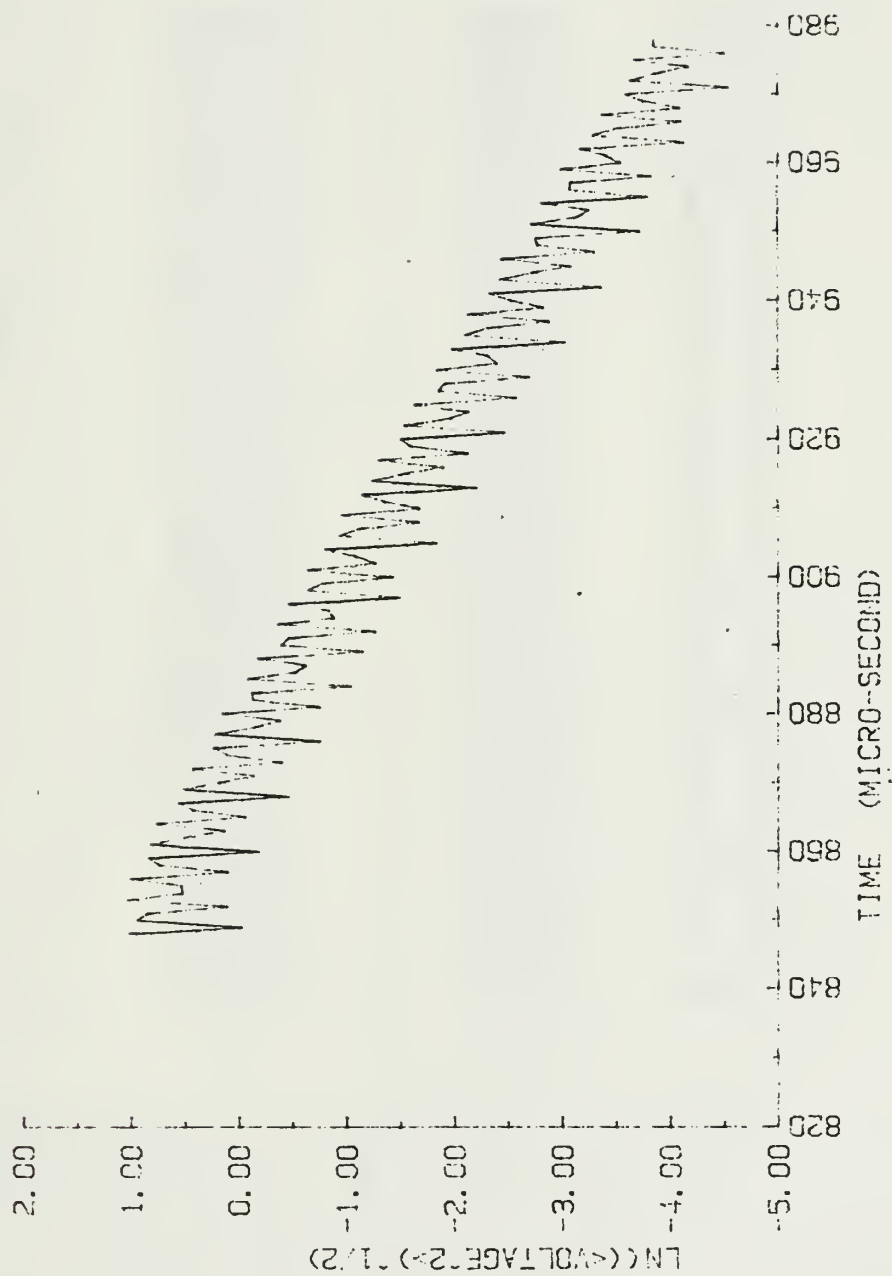
	TIME (SEC.)	VOLT
J= 1	.000850	2.59613424
J= 2	.000853	2.79951389
J= 3	.000856	2.71931729
J= 4	.000859	2.30353012
J= 5	.000861	2.28819448
J= 6	.000864	2.12830884
J= 7	.000867	1.75489017
J= 8	.000869	1.69369035
J= 9	.000872	1.53057604
J= 10	.000875	1.26327075
J= 11	.000877	1.25842342
J= 12	.000880	1.16341394
J= 13	.000883	.88792004
J= 14	.000885	.91407904
J= 15	.000888	.83815154
J= 16	.000890	.67148380
J= 17	.000893	.69302453
J= 18	.000896	.62557893
J= 19	.000898	.52693121
J= 20	.000901	.52798153
J= 21	.000904	.44685568
J= 22	.000906	.39219574
J= 23	.000909	.38373103
J= 24	.000912	.31615344
J= 25	.000914	.29276868
J= 26	.000917	.27238943
J= 27	.000920	.22175888
J= 28	.000922	.21624870
J= 29	.000925	.19514738
J= 30	.000927	.15660140
J= 31	.000930	.15839034
J= 32	.000933	.13726616
J= 33	.000935	.12214950
J= 34	.000938	.11817995
J= 35	.000941	.09757817
J= 36	.000943	.08842511
J= 37	.000946	.08691950
J= 38	.000949	.06372598
J= 39	.000951	.06676077
J= 40	.000954	.06005831
J= 41	.000956	.04650806
J= 42	.000959	.05024440
J= 43	.000962	.04182105
J= 44	.000964	.03720887
J= 45	.000967	.03414674
J= 46	.000970	.02744085
J= 47	.000972	.02630589
J= 48	.000975	.02539685

DATA3

SLOPE = $-3.7566221 \times 10^{-2} \text{ s}^{-1}$
CORRELATION
COEFFICIENT = -0.9893605



DATA3



DATA4

LOCAL MAXIMA

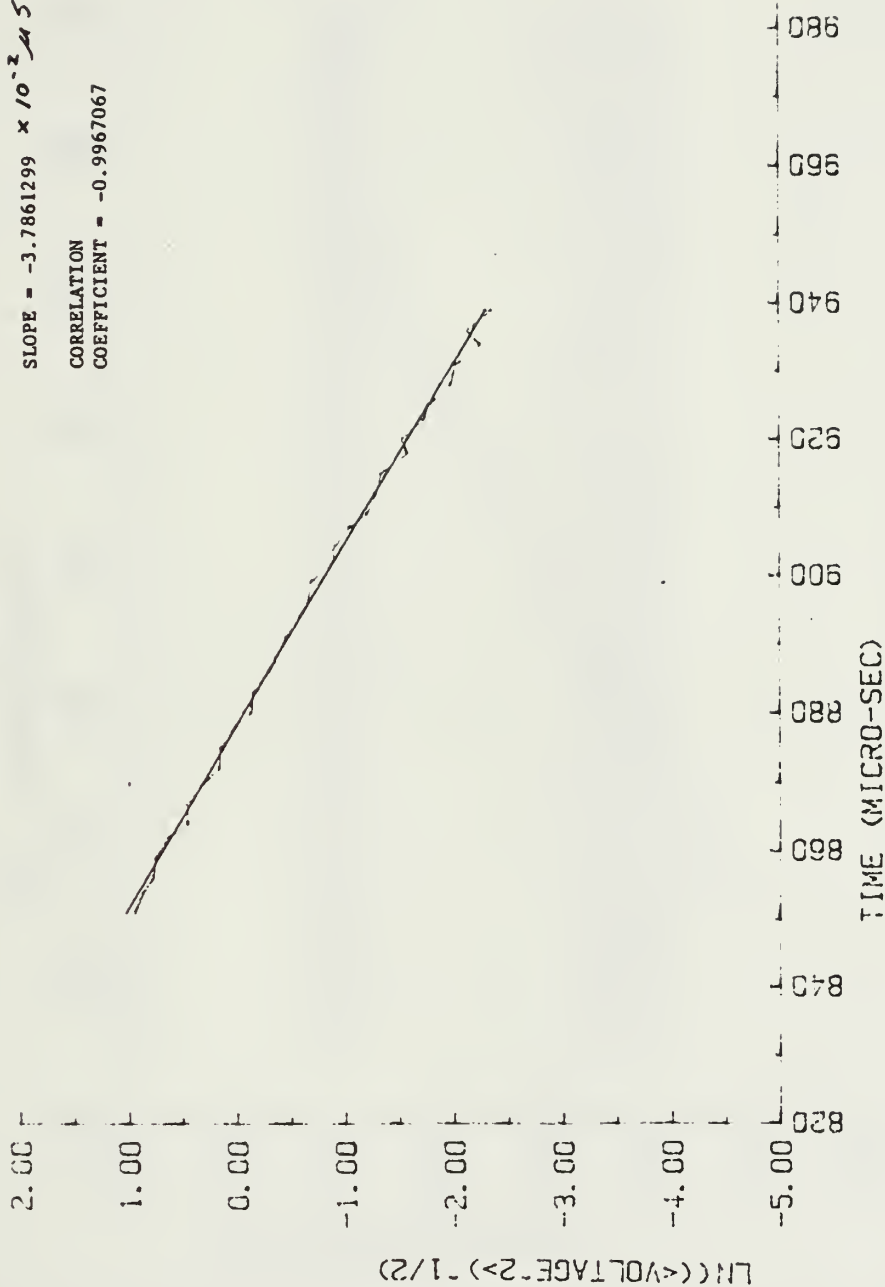
	TIME (SEC.)	VOLT
J= 1	.000851	2.56653872
J= 2	.000854	2.36947695
J= 3	.000856	2.16645909
J= 4	.000859	2.12358306
J= 5	.000862	1.87433321
J= 6	.000864	1.56400352
J= 7	.000867	1.58445764
J= 8	.000870	1.34618869
J= 9	.000872	1.16810744
J= 10	.000875	1.16227277
J= 11	.000878	1.01832215
J= 12	.000880	.86677852
J= 13	.000883	.85511695
J= 14	.000886	.73137337
J= 15	.000888	.68510510
J= 16	.000891	.63408674
J= 17	.000894	.55311301
J= 18	.000896	.51156720
J= 19	.000899	.50001800
J= 20	.000902	.40213431
J= 21	.000904	.40505061
J= 22	.000907	.34963123
J= 23	.000909	.29629884
J= 24	.000912	.27229580
J= 25	.000915	.26062041
J= 26	.000918	.20316496
J= 27	.000920	.21664718
J= 28	.000923	.17491426
J= 29	.000925	.16858826
J= 30	.000928	.13725888
J= 31	.000931	.13128214
J= 32	.000934	.10402404
J= 33	.000936	.11898319
J= 34	.000939	.09447222
J= 35	.000941	.10088607
J= 36	.000944	.08064738
J= 37	.000946	.08919081
J= 38	.000951	.07902531
J= 39	.000956	.07198611
J= 40	.000962	.06824954
J= 41	.000967	.06494613
J= 42	.000972	.06486139

DATA4

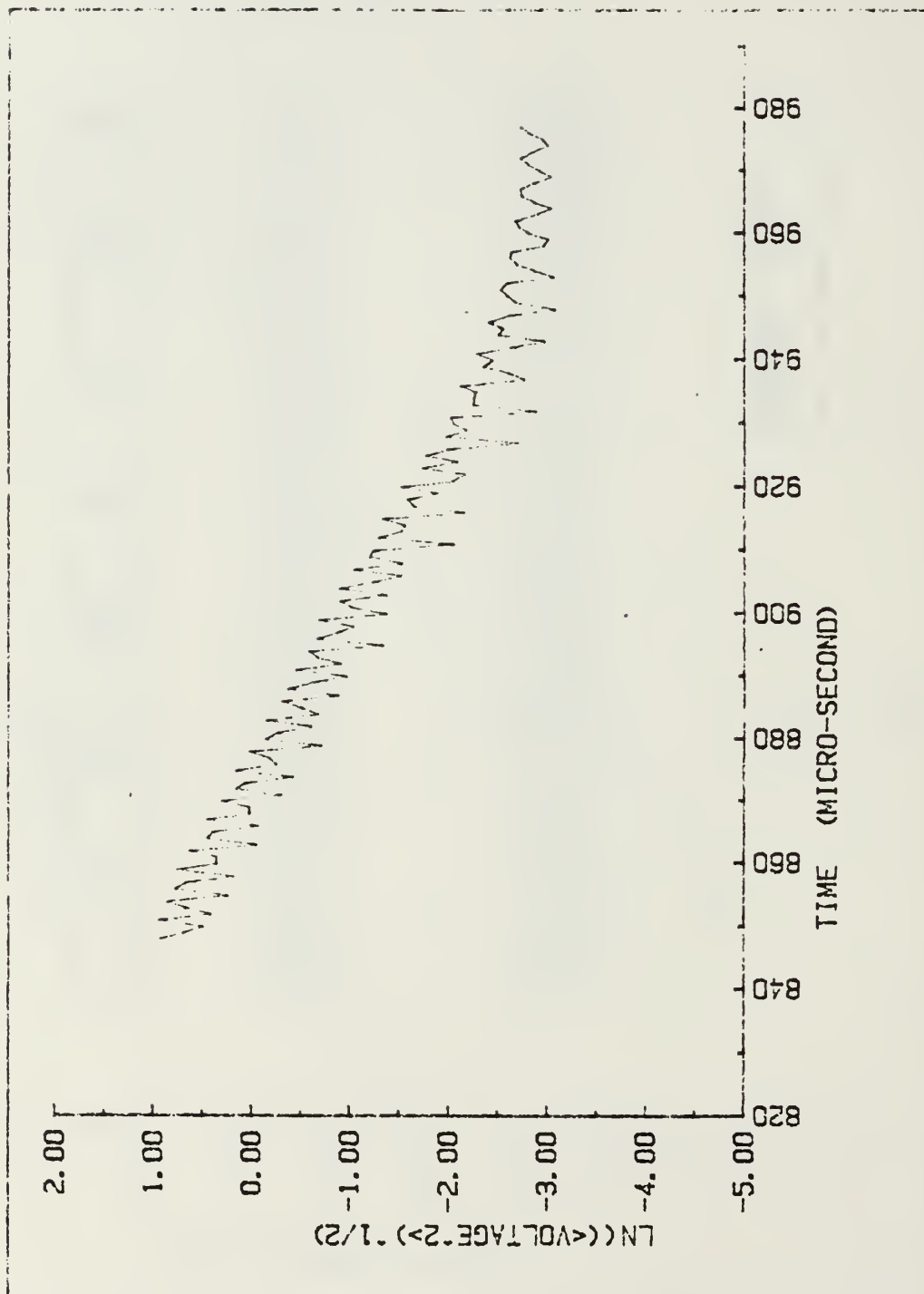
SLOPE = $-3.7861299 \times 10^{-2} \mu s^{-1}$

CORRELATION

COEFFICIENT = -0.9967067



DATA4



DATA6

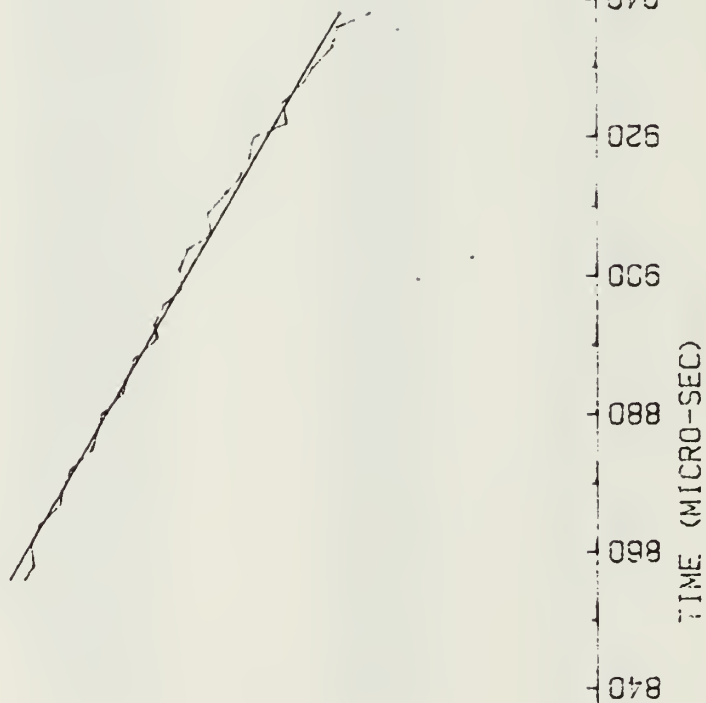
LOCAL MAXIMA

	TIME (SEC.)	VOLT
J= 0	.000856	1.25228910
J= 1	.000858	1.15177081
J= 2	.000861	1.18948224
J= 3	.000864	1.09117001
J= 4	.000867	.90368579
J= 5	.000869	.88389592
J= 6	.000872	.82582080
J= 7	.000875	.67306166
J= 8	.000877	.65203988
J= 9	.000880	.61720985
J= 10	.000883	.51030187
J= 11	.000885	.49017548
J= 12	.000888	.45939090
J= 13	.000891	.36963766
J= 14	.000893	.38264866
J= 15	.000896	.34631777
J= 16	.000898	.29783217
J= 17	.000901	.30169521
J= 18	.000904	.27828043
J= 19	.000906	.22592034
J= 20	.000909	.23441843
J= 21	.000912	.19708881
J= 22	.000914	.17593180
J= 23	.000917	.15962456
J= 24	.000920	.15278743
J= 25	.000922	.11290704
J= 26	.000925	.11862546
J= 27	.000928	.09622889
J= 28	.000930	.08890444
J= 29	.000933	.07437742
J= 30	.000936	.07099296
J= 31	.000938	.05306600
J= 32	.000941	.05723635
J= 33	.000944	.04538722
J= 34	.000946	.04454211
J= 35	.000949	.03964846
J= 36	.000952	.03464102
J= 37	.000957	.03052868
J= 38	.000960	.02545584
J= 39	.000962	.02668333
J= 40	.000965	.02660827
J= 41	.000967	.02537716
J= 42	.000972	.02289105
J= 43	.000977	.02244994

DATA6

LM((<VOLTAGE^2>)^1/2)

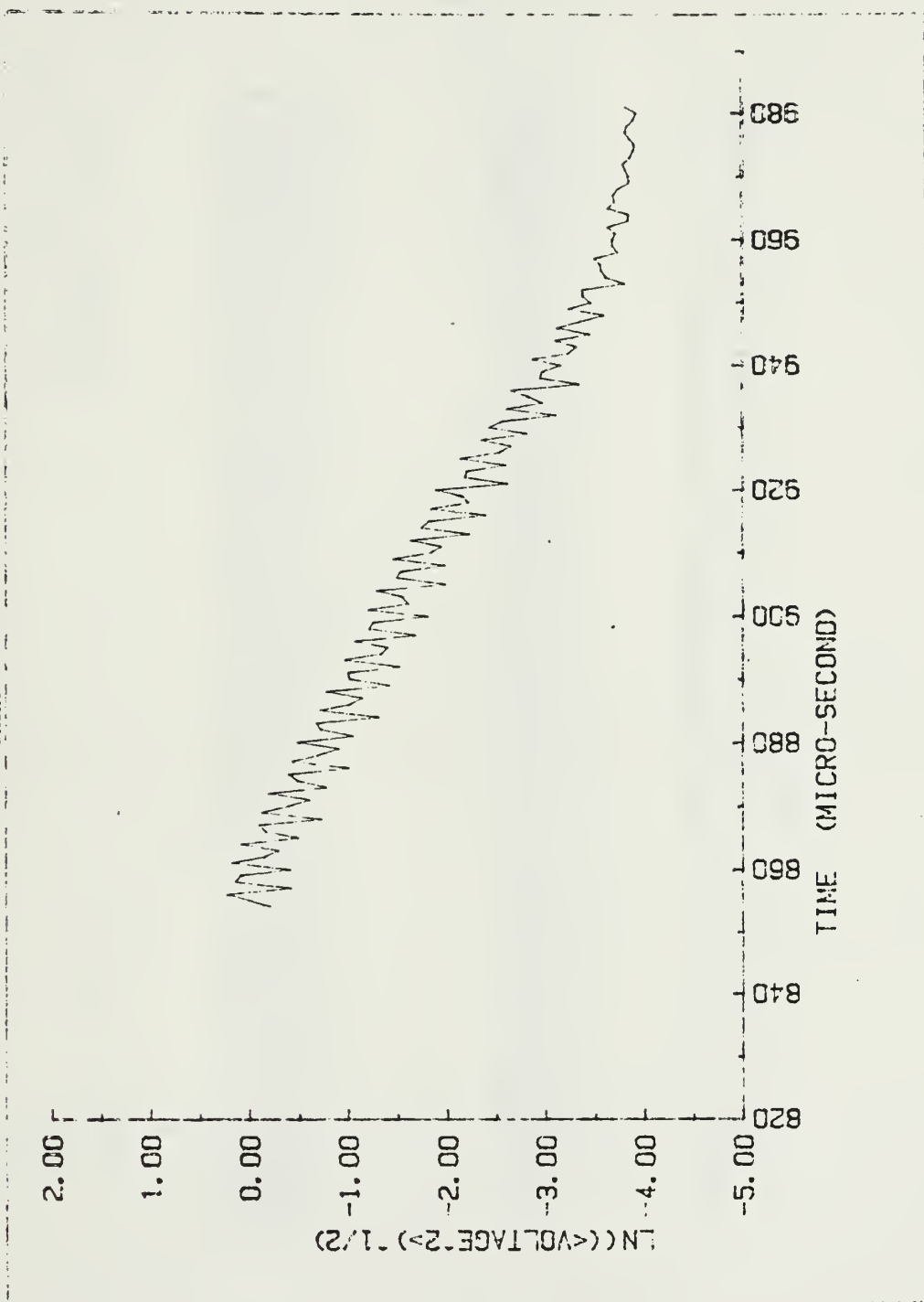
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00



SLOPE = -3.691128 $\times 10^{-2}$ μs^{-1}

CORRELATION
COEFFICIENT = -0.972798

DATA6



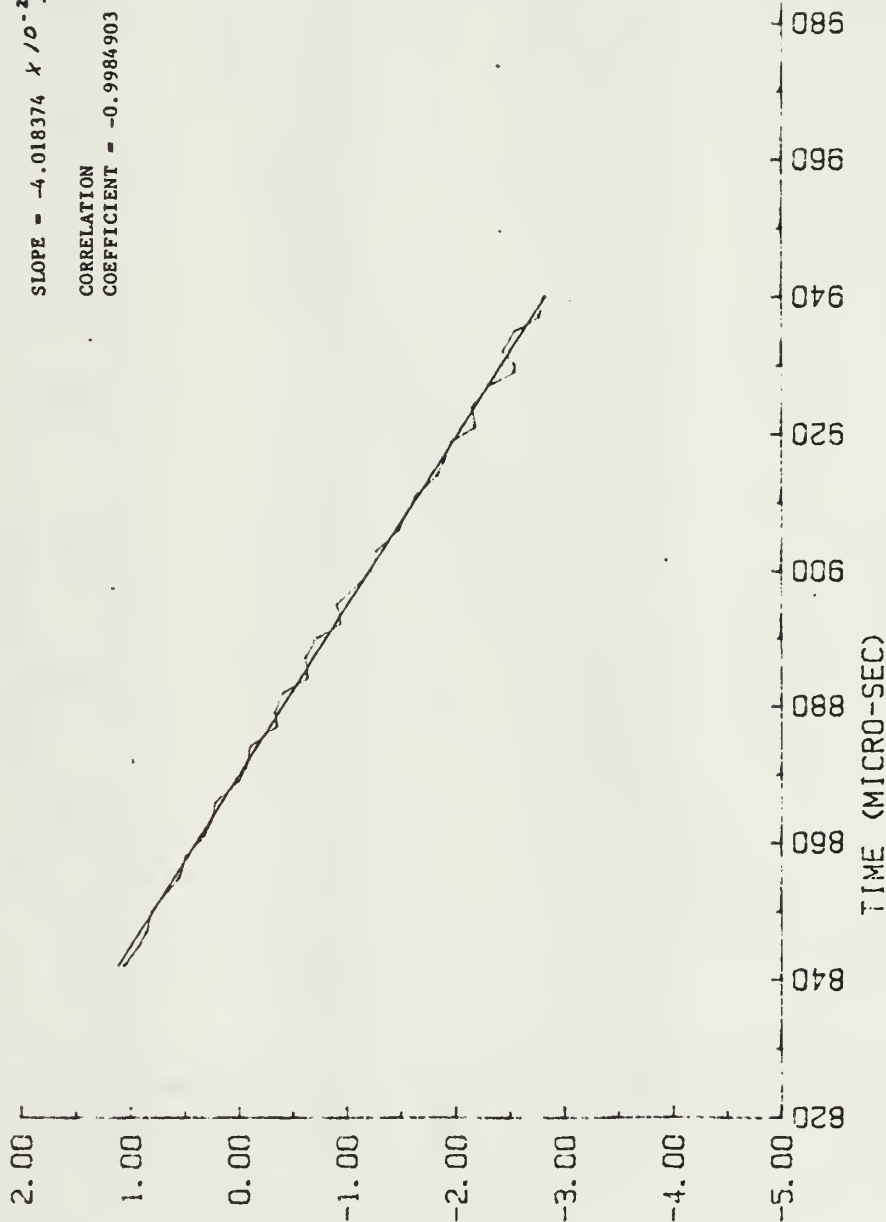
DATA7

LOCAL MAXIMA

	TIME (SEC.)	VOLT
J= 1	.000842	2.86286570
J= 2	.000845	2.50100780
J= 3	.000847	2.32526128
J= 4	.000850	2.22915231
J= 5	.000853	1.91358303
J= 6	.000855	1.71812689
J= 7	.000858	1.61507895
J= 8	.000861	1.36750868
J= 9	.000863	1.28786645
J= 10	.000866	1.23103209
J= 11	.000869	.99214918
J= 12	.000871	.92762061
J= 13	.000874	.89672738
J= 14	.000877	.69782519
J= 15	.000879	.71769074
J= 16	.000882	.65748004
J= 17	.000884	.52524280
J= 18	.000887	.53844220
J= 19	.000890	.47933287
J= 20	.000892	.38631593
J= 21	.000895	.40139756
J= 22	.000898	.32625144
J= 23	.000900	.29161619
J= 24	.000903	.27683930
J= 25	.000906	.22521101
J= 26	.000908	.21326040
J= 27	.000911	.19503846
J= 28	.000914	.15912259
J= 29	.000916	.14966630
J= 30	.000919	.14014278
J= 31	.000921	.11207141
J= 32	.000924	.11644741
J= 33	.000927	.09979980
J= 34	.000929	.07771744
J= 35	.000930	.07771744
J= 36	.000932	.08763561
J= 37	.000935	.07797435
J= 38	.000937	.06260990
J= 39	.000940	.06000000
J= 40	.000943	.05215362
J= 41	.000945	.04427189
J= 42	.000948	.04147288
J= 43	.000951	.03898718
J= 44	.000953	.04472136
J= 45	.000956	.03405877
J= 46	.000958	.03033150
J= 47	.000963	.03162278
J= 48	.000966	.02366432
J= 49	.000969	.03033150
J= 50	.000971	.02683282
J= 51	.000975	.02683282
J= 52	.000979	.02898275
J= 53	.000981	.02607681

DATA7

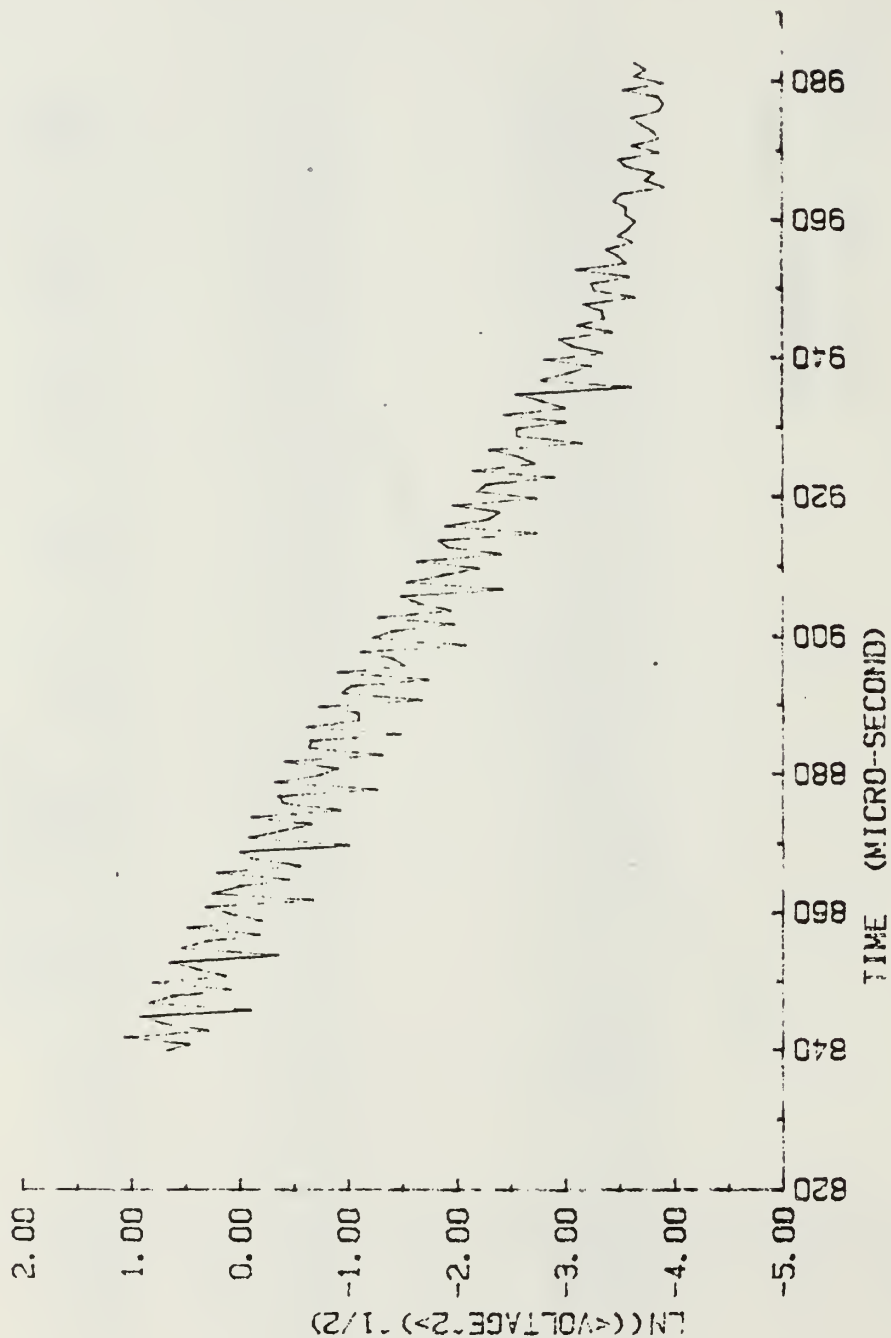
LN((VOLTAGE²)^{1/2})



SLOPE = $-4.018374 \times 10^{-2} \mu\text{S}^{-1}$

CORRELATION
COEFFICIENT = -0.9984903

DATA



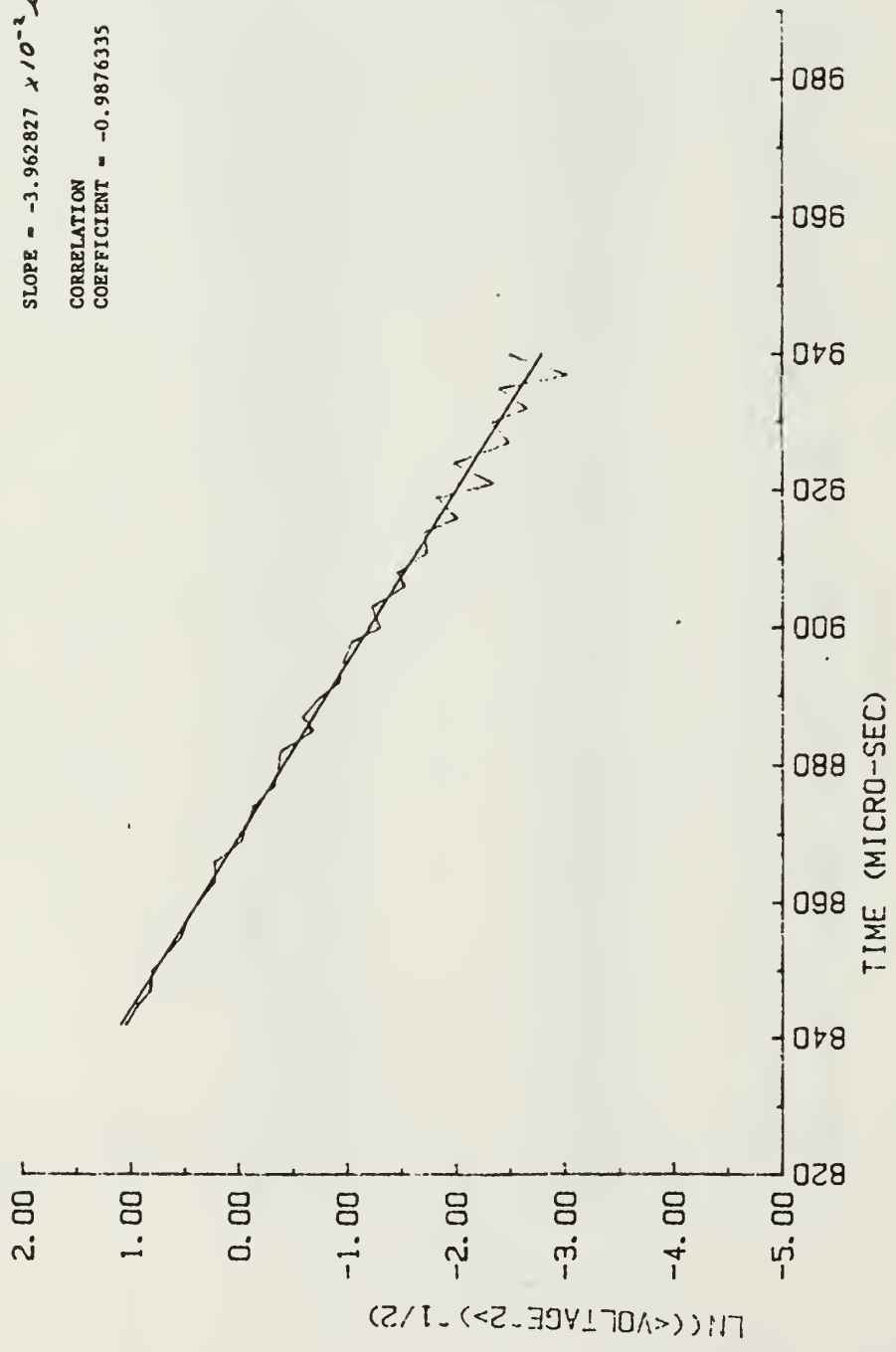
DATA8

LOCAL MAXIMA

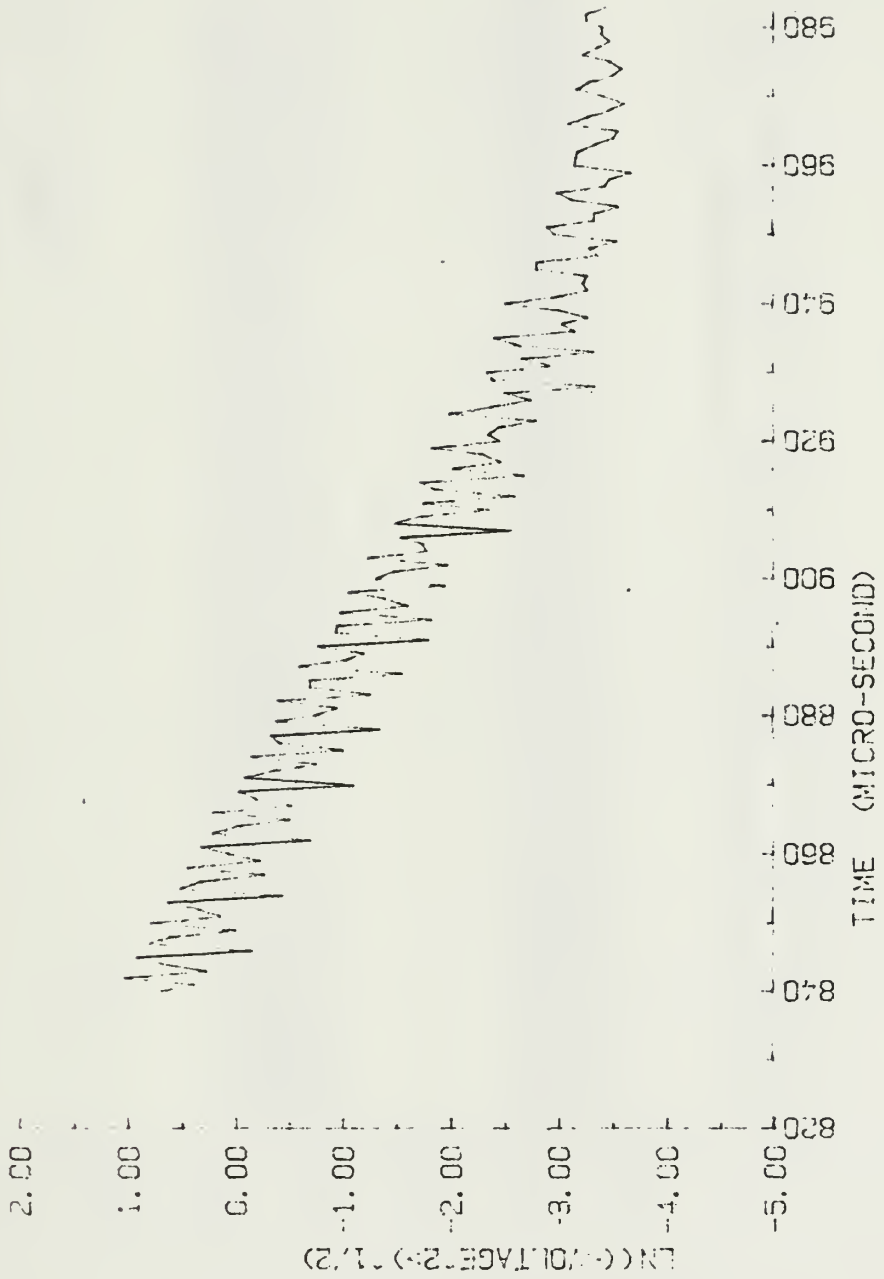
	TIME (SEC.)	VOLT
J= 1	.000842	2.82097855
J= 2	.000845	2.51604451
J= 3	.000847	2.25417391
J= 4	.000850	2.22184608
J= 5	.000853	1.89121654
J= 6	.000855	1.69882901
J= 7	.000858	1.57907568
J= 8	.000861	1.38683813
J= 9	.000863	1.24620223
J= 10	.000866	1.24209500
J= 11	.000869	.97068017
J= 12	.000871	.93496524
J= 13	.000874	.86755980
J= 14	.000877	.71880456
J= 15	.000879	.69228607
J= 16	.000882	.67768724
J= 17	.000885	.50009999
J= 18	.000887	.55375085
J= 19	.000890	.46255810
J= 20	.000892	.39489239
J= 21	.000895	.37884034
J= 22	.000898	.34919908
J= 23	.000900	.27055499
J= 24	.000903	.29305290
J= 25	.000906	.21549942
J= 26	.000908	.22973898
J= 27	.000911	.17567015
J= 28	.000914	.18083141
J= 29	.000916	.13326665
J= 30	.000919	.16204938
J= 31	.000921	.09591663
J= 32	.000924	.13834739
J= 33	.000927	.08282512
J= 34	.000930	.09705668
J= 35	.000932	.07014271
J= 36	.000935	.09099451
J= 37	.000937	.04857983
J= 38	.000940	.08221922
J= 39	.000943	.04000000
J= 40	.000945	.06148170
J= 41	.000948	.03768289
J= 42	.000951	.05585696
J= 43	.000956	.05118594
J= 44	.000960	.04312772
J= 45	.000966	.04604346
J= 46	.000971	.04242641
J= 47	.000976	.04024922
J= 48	.000979	.03376389
J= 49	.000982	.03898718

DATA8

SLOPE = $-3.962827 \times 10^{-2} \mu s^{-1}$
CORRELATION
COEFFICIENT = -0.9876335



DATA8



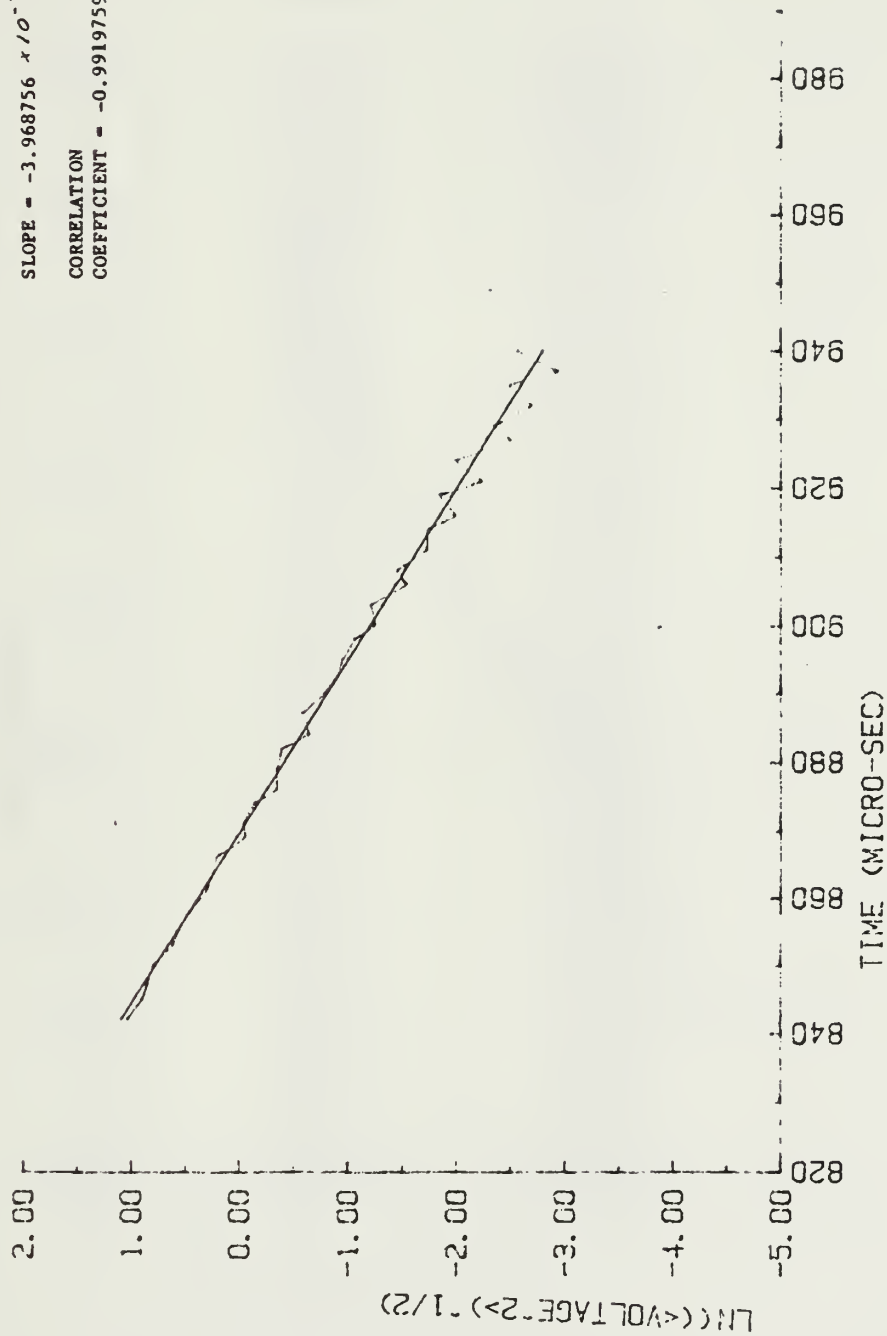
DATA9

LOCAL MAXIMA

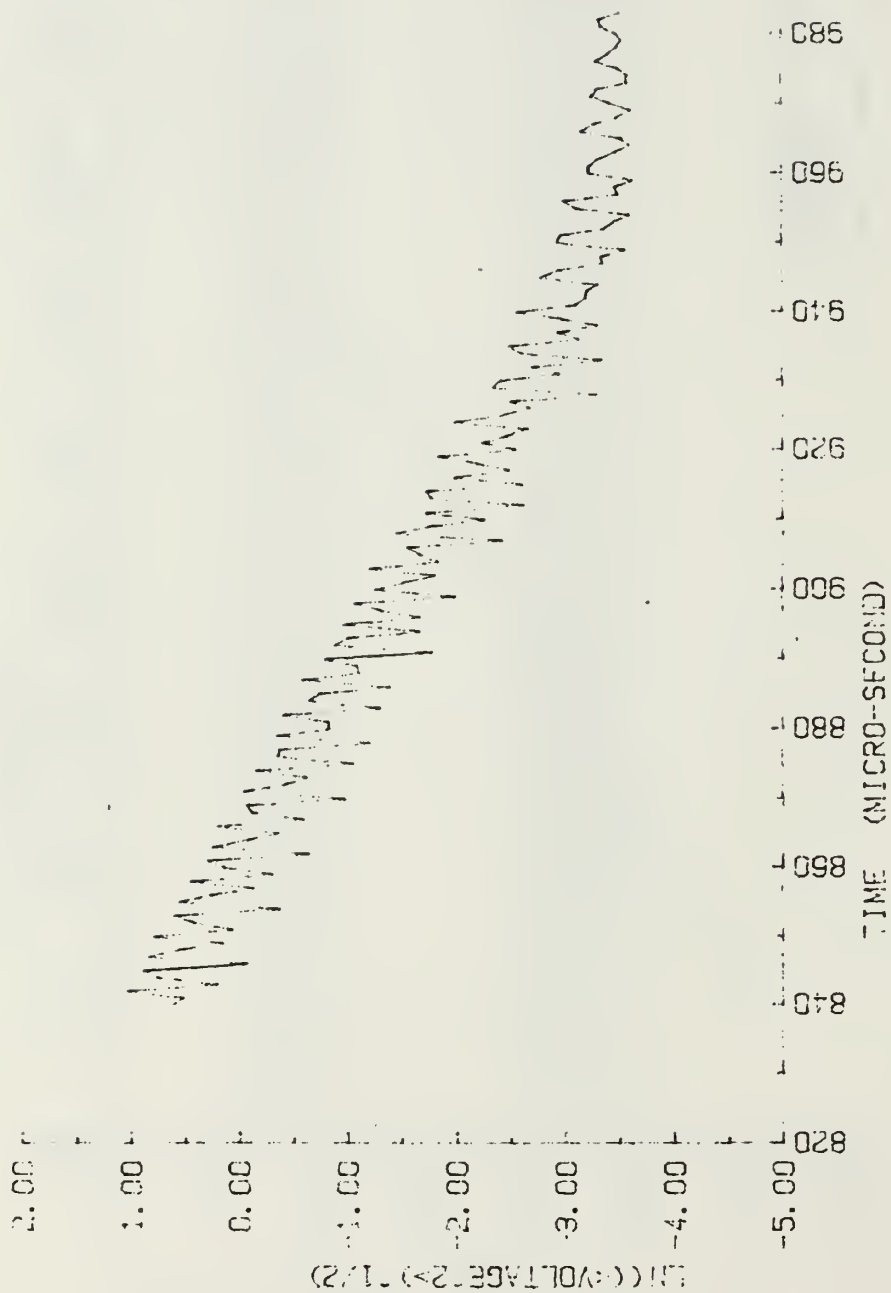
	TIME (SEC.)	VOLT
J= 1	.000842	2.79044369
J= 2	.000845	2.42803954
J= 3	.000847	2.32221102
J= 4	.000850	2.21119696
J= 5	.000853	1.82984371
J= 6	.000855	1.74683943
J= 7	.000858	1.56490511
J= 8	.000861	1.34148574
J= 9	.000863	1.27793897
J= 10	.000866	1.22861223
J= 11	.000869	.93245053
J= 12	.000871	.95596653
J= 13	.000874	.85806760
J= 14	.000876	.69895350
J= 15	.000879	.70414203
J= 16	.000882	.66741891
J= 17	.000884	.52178923
J= 18	.000887	.55760918
J= 19	.000890	.45095454
J= 20	.000892	.41226205
J= 21	.000895	.37968408
J= 22	.000898	.34137370
J= 23	.000900	.28326666
J= 24	.000903	.29686361
J= 25	.000906	.21143320
J= 26	.000908	.23397436
J= 27	.000911	.17674841
J= 28	.000914	.17593180
J= 29	.000916	.13588230
J= 30	.000919	.15882065
J= 31	.000921	.10605659
J= 32	.000924	.13644046
J= 33	.000927	.08153527
J= 34	.000929	.09528903
J= 35	.000932	.06729042
J= 36	.000935	.08275264
J= 37	.000937	.05276362
J= 38	.000940	.07694154
J= 39	.000945	.06216108
J= 40	.000948	.03544009
J= 41	.000950	.05351635
J= 42	.000956	.05019960
J= 43	.000958	.03136877
J= 44	.000960	.03969887
J= 45	.000966	.04270831
J= 46	.000971	.03878144
J= 47	.000976	.03720215
J= 48	.000982	.03644173

DATA9

SLOPE = -3.968756×10^{-2} sec⁻¹
CORRELATION
COEFFICIENT = -0.9919759



DATA9



DATA10

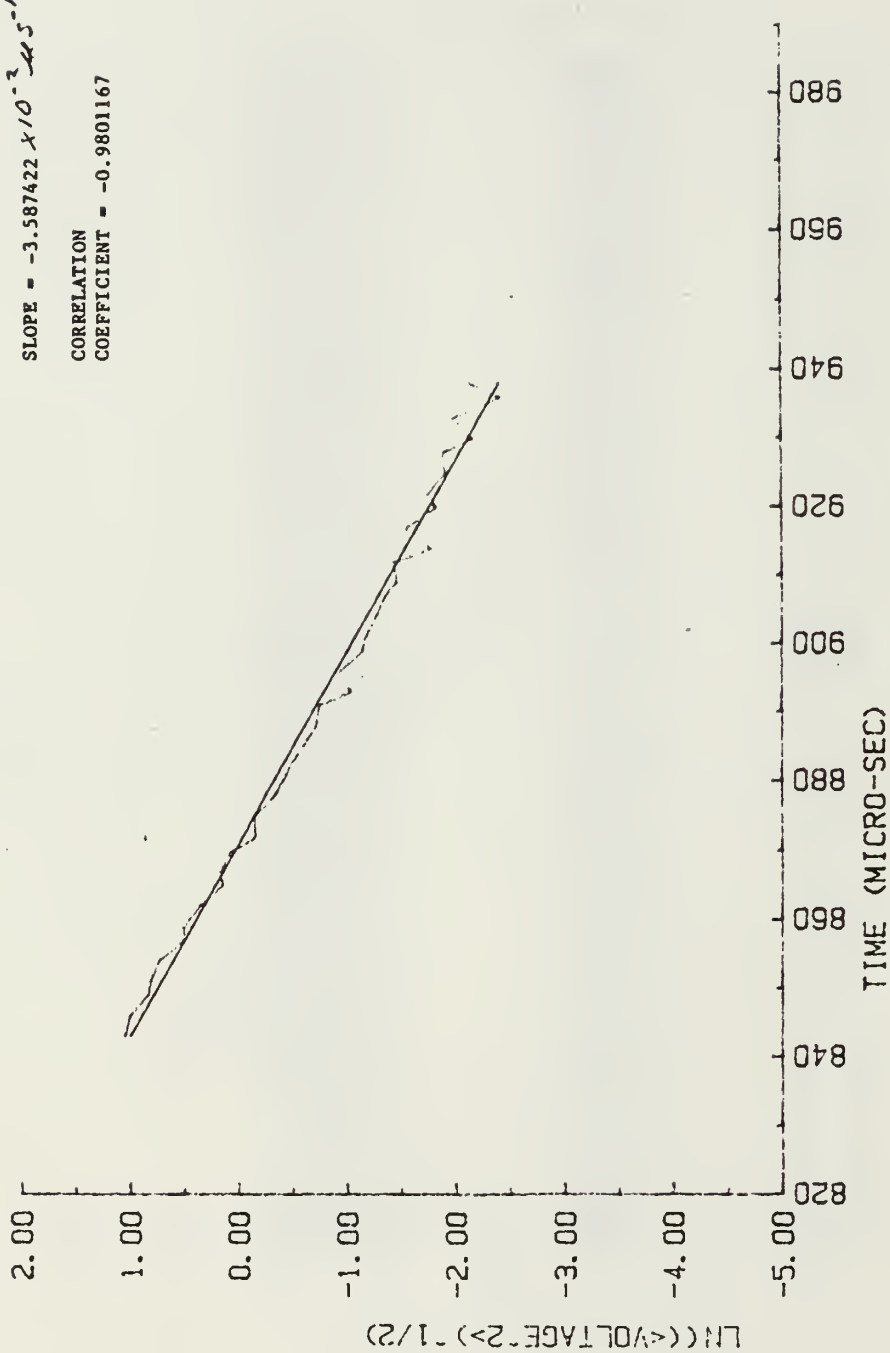
LOCAL MAXIMA

	TIME (SEC.)	VOLT
J= 1	.000843	2.82483256
J= 2	.000846	2.68796959
J= 3	.000849	2.28436074
J= 4	.000851	2.22633522
J= 5	.000854	2.06975953
J= 6	.000857	1.64075790
J= 7	.000859	1.63980578
J= 8	.000862	1.41303574
J= 9	.000865	1.14007171
J= 10	.000867	1.16729088
J= 11	.000870	1.05813799
J= 12	.000872	.84032702
J= 13	.000875	.84959049
J= 14	.000878	.70170400
J= 15	.000880	.65438368
J= 16	.000883	.59486385
J= 17	.000886	.52219776
J= 18	.000888	.48041388
J= 19	.000891	.46750668
J= 20	.000893	.34809266
J= 21	.000896	.38650097
J= 22	.000899	.31211697
J= 23	.000901	.30389472
J= 24	.000904	.27546415
J= 25	.000907	.25276768
J= 26	.000909	.22705066
J= 27	.000912	.23514464
J= 28	.000914	.16651727
J= 29	.000917	.20900359
J= 30	.000920	.15851498
J= 31	.000922	.17102047
J= 32	.000925	.14651109
J= 33	.000928	.14893119
J= 34	.000930	.11303539
J= 35	.000933	.13704379
J= 36	.000936	.08780945
J= 37	.000938	.11675616
J= 38	.000941	.08147085
J= 39	.000943	.08969392
J= 40	.000946	.06491148
J= 41	.000949	.08607845
J= 42	.000951	.04629255
J= 43	.000954	.07623975
J= 44	.000957	.03974292
J= 45	.000959	.06088514
J= 46	.000962	.03406611
J= 47	.000965	.05410638
J= 48	.000970	.05094605
J= 49	.000975	.04145479
J= 50	.000981	.03519943

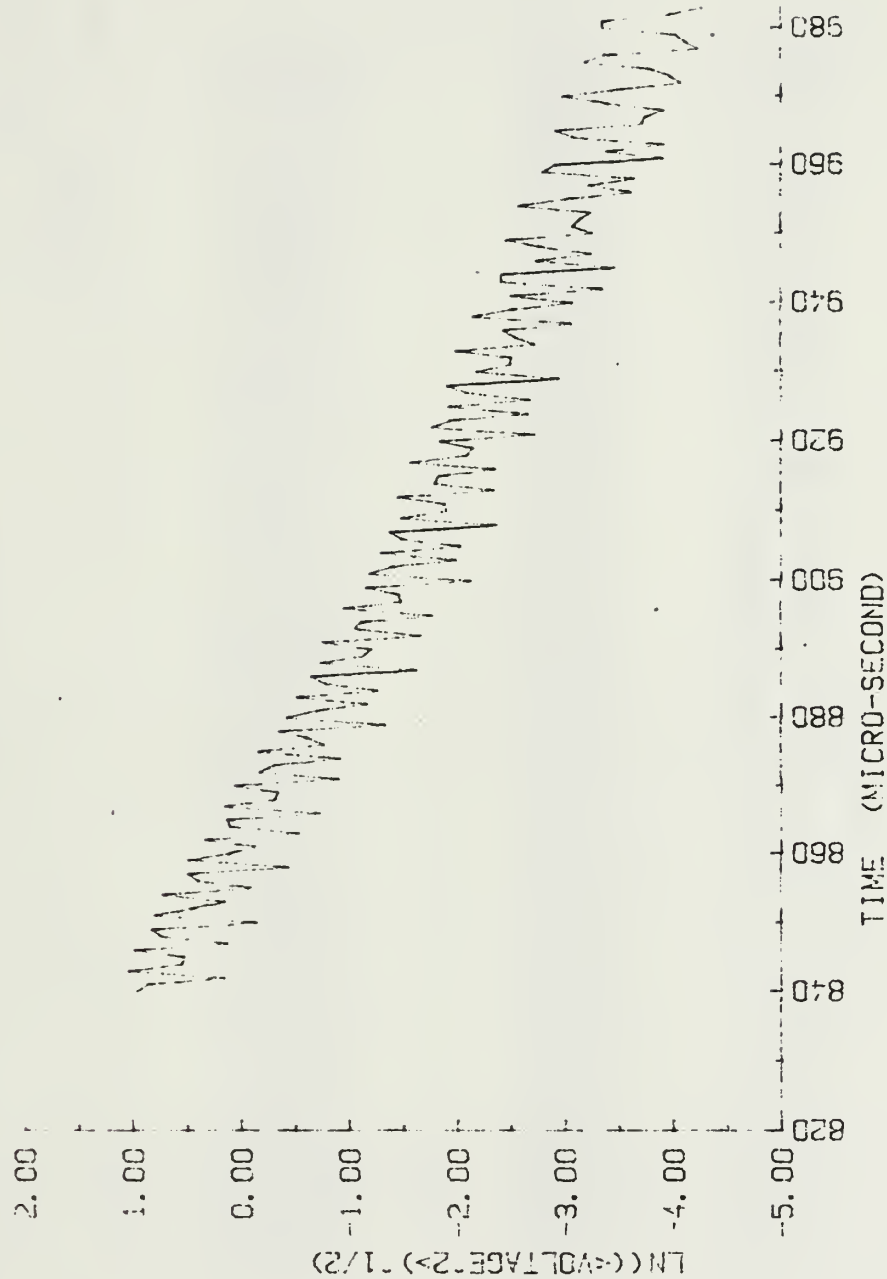
DATA10

SLOPE = $-3.587422 \times 10^{-3} \text{ } 45^{-1}$

CORRELATION
COEFFICIENT = -0.9801167



DATA10



DATA11

LOCAL MAXIMA

	TIME (SEC.)	VOLT
J= 1	.000842	2.86878511
J= 2	.000845	2.45918360
J= 3	.000847	2.46472879
J= 4	.000850	2.30432289
J= 5	.000853	1.90630533
J= 6	.000855	1.82231062
J= 7	.000858	1.67886867
J= 8	.000861	1.35363215
J= 9	.000863	1.35458333
J= 10	.000866	1.25505697
J= 11	.000869	.98838859
J= 12	.000871	.97666371
J= 13	.000874	.90785902
J= 14	.000876	.71765730
J= 15	.000879	.74785025
J= 16	.000882	.66050889
J= 17	.000884	.57047349
J= 18	.000887	.55370028
J= 19	.000890	.48289129
J= 20	.000892	.41059956
J= 21	.000895	.41605769
J= 22	.000898	.32057448
J= 23	.000900	.30780513
J= 24	.000903	.28227646
J= 25	.000906	.22460632
J= 26	.000908	.21927152
J= 27	.000911	.20830747
J= 28	.000913	.15592306
J= 29	.000916	.16838052
J= 30	.000919	.13988567
J= 31	.000921	.13389548
J= 32	.000924	.12325583
J= 33	.000927	.10710742
J= 34	.000929	.09277931
J= 35	.000932	.09138928
J= 36	.000935	.07863841
J= 37	.000937	.07858753
J= 38	.000940	.06437391
J= 39	.000942	.06794115
J= 40	.000945	.04923413
J= 41	.000948	.05761944
J= 42	.000950	.04489989
J= 43	.000953	.05374012
J= 44	.000956	.03979950
J= 45	.000958	.04543127
J= 46	.000961	.03521363
J= 47	.000963	.04354308
J= 48	.000966	.03274141
J= 49	.000969	.04445222
J= 50	.000972	.03762978
J= 51	.000975	.04049691
J= 52	.000979	.03929377
J= 53	.000982	.03784178

DATA11

LN((VOLTAGE-2)^{1/2})

2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00

TIME (MICRO-SEC)

820 840 860 880 900 920 940 960 980

SLOPE = $-3.9208838 \times 10^{-2}$ 45-1
CORRELATION
COEFFICIENT = -0.9985596

DATA11

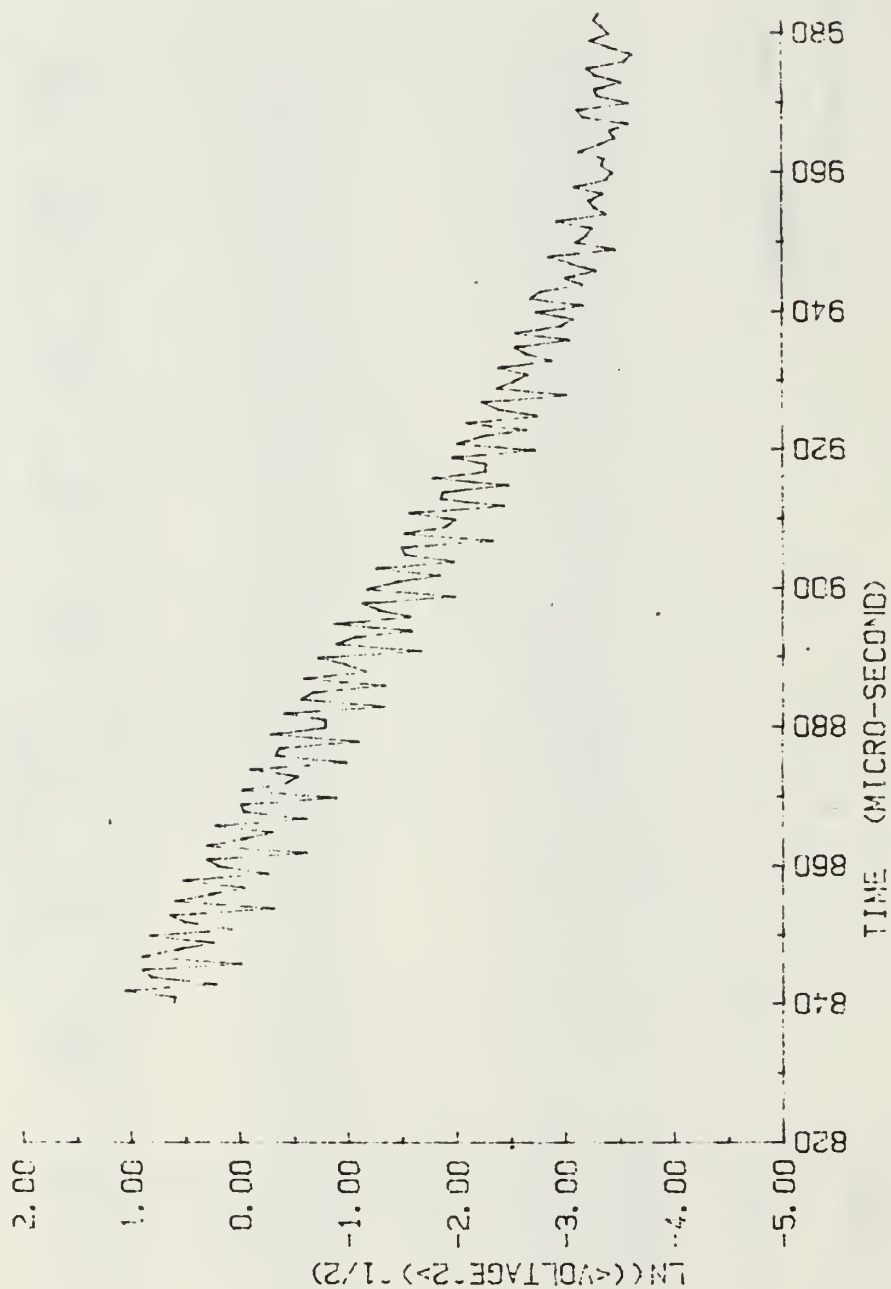


TABLE 2

AGGREGATE REFLECTION

FREQUENCY: 185kHz

DATA SET	SAMPLE TIME (μs)	NUMBER OF SAMPLES IN DATA SET	SLOPE ($\times 10^{-2}$)	CORRELATION COEFFICIENT
DATA1	822-940	100	-3.2230	-0.9355
DATA2	816-940	100	-3.1460	-0.9657
DATA5	852-940	100	-3.9916	-0.9919
DATA12	840-940	50	-2.2354	-0.9284
DATA13	840-940	100	-2.2395	-0.9261
DATA14	840-940	50	-2.5359	-0.8356
DATA15*	540-580	50	-4.4800	-0.9679
DATA16**	760-840	50	-3.3925	-0.9163
DATA17***	1000-1090	50	-3.9117	-0.9673

MEAN SLOPE = $-3.24 \times 10^{-2} \mu s^{-1}$ $\sigma = 0.80 \times 10^{-2} \mu s^{-1}$

* Distance from F-41 active face to sediment surface = 30 cm

** " " " " " " " " = 50 cm

*** " " " " " " " " = 70 cm

With DATA15 excluded from the selected samples;

MEAN SLOPE = $-3.08 \times 10^{-2} \mu s^{-1}$ $\sigma = 0.69 \times 10^{-2} \mu s^{-1}$

DATA1

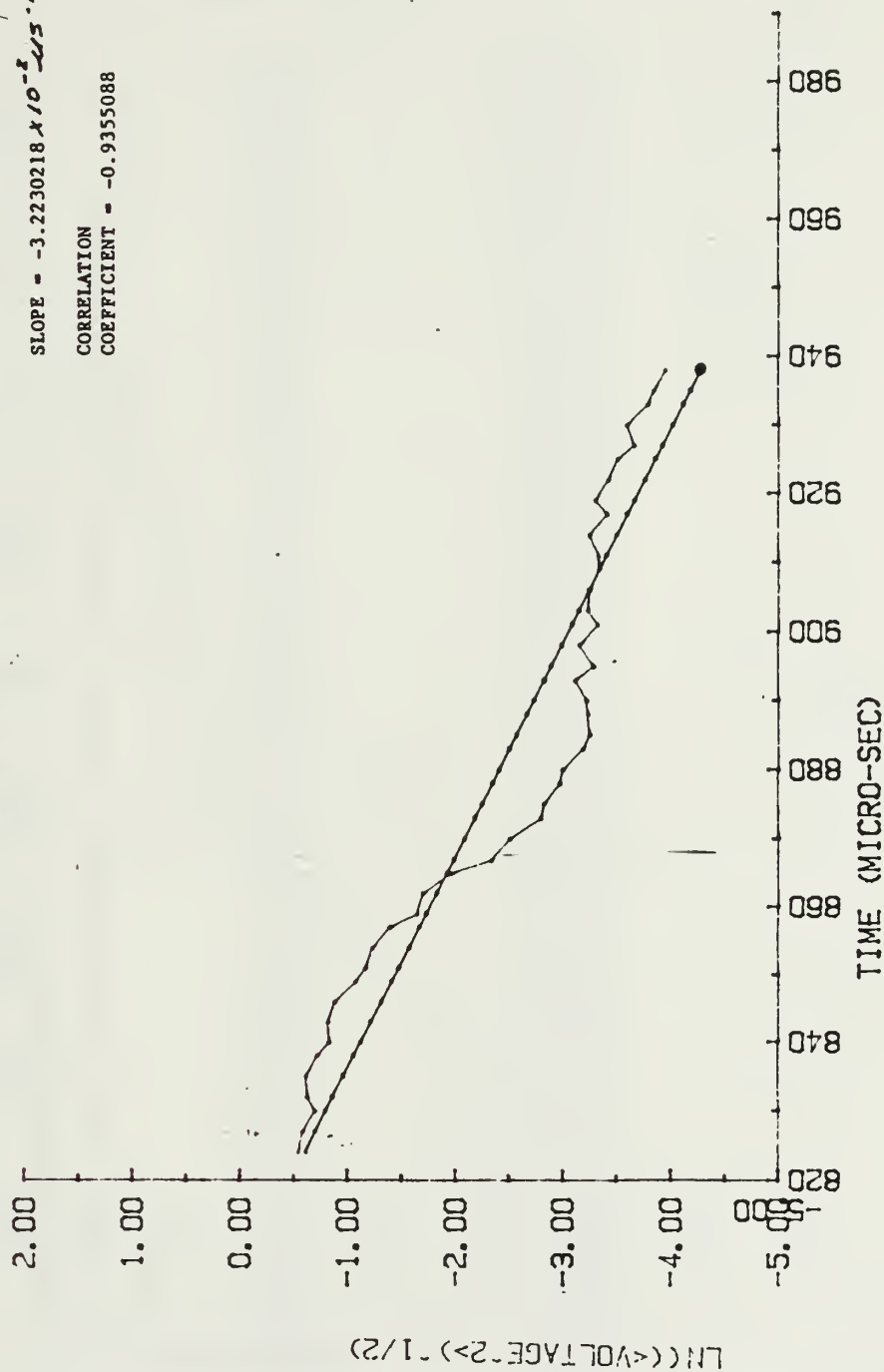
LOCAL MAXIMA

	TIME (SEC.)	VOLT
J= 1	.000824	.57628022
J= 2	.000827	.55382207
J= 3	.000830	.49387445
J= 4	.000832	.53072987
J= 5	.000835	.53843403
J= 6	.000838	.48344567
J= 7	.000840	.43328920
J= 8	.000843	.43946235
J= 9	.000846	.41009449
J= 10	.000849	.34025304
J= 11	.000851	.31111625
J= 12	.000854	.28984644
J= 13	.000857	.24713019
J= 14	.000859	.19278288
J= 15	.000862	.18139515
J= 16	.000865	.13988116
J= 17	.000867	.09621143
J= 18	.000870	.08093312
J= 19	.000873	.06076652
J= 20	.000875	.05901839
J= 21	.000878	.05104087
J= 22	.000880	.04949232
J= 23	.000883	.04113952
J= 24	.000885	.03846089
J= 25	.000888	.03946568
J= 26	.000890	.03787079
J= 27	.000893	.04427302
J= 28	.000895	.03733323
J= 29	.000898	.04256642
J= 30	.000901	.03588398
J= 31	.000903	.03924589
J= 32	.000906	.03847207
J= 33	.000909	.03540523
J= 34	.000911	.03558834
J= 35	.000914	.03876003
J= 36	.000917	.03284144
J= 37	.000919	.03671294
J= 38	.000922	.03248908
J= 39	.000925	.02973298
J= 40	.000927	.02357069
J= 41	.000930	.02736933
J= 42	.000933	.02255394
J= 43	.000935	.02129906
J= 44	.000938	.01910393
J= 45	.000941	.01982347
J= 46	.000944	.01525287
J= 47	.000947	.01464582
J= 48	.000949	.01207394
J= 49	.000953	.01541623
J= 50	.000956	.01516905
J= 51	.000958	.01808922
J= 52	.000961	.01612328
J= 53	.000964	.01986001
J= 54	.000967	.02189383
J= 55	.000970	.02557577
J= 56	.000973	.02016284
J= 57	.000975	.02220113
J= 58	.000978	.02042964

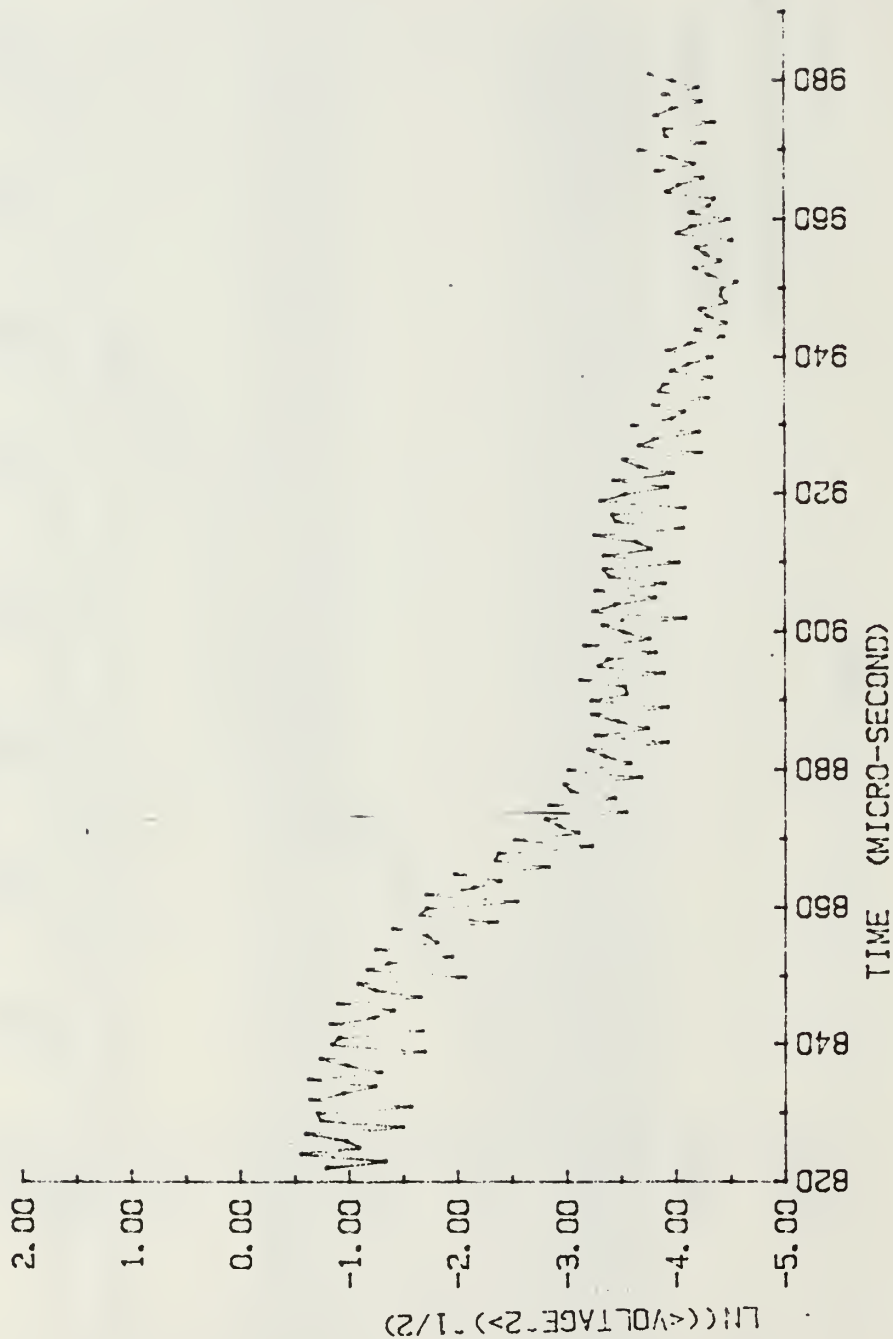
DATAL

SLOPE = $-3.2230218 \times 10^{-2}$ *45.1*

CORRELATION
COEFFICIENT = -0.935088



DATA



DATA2

LOCAL MAXIMA

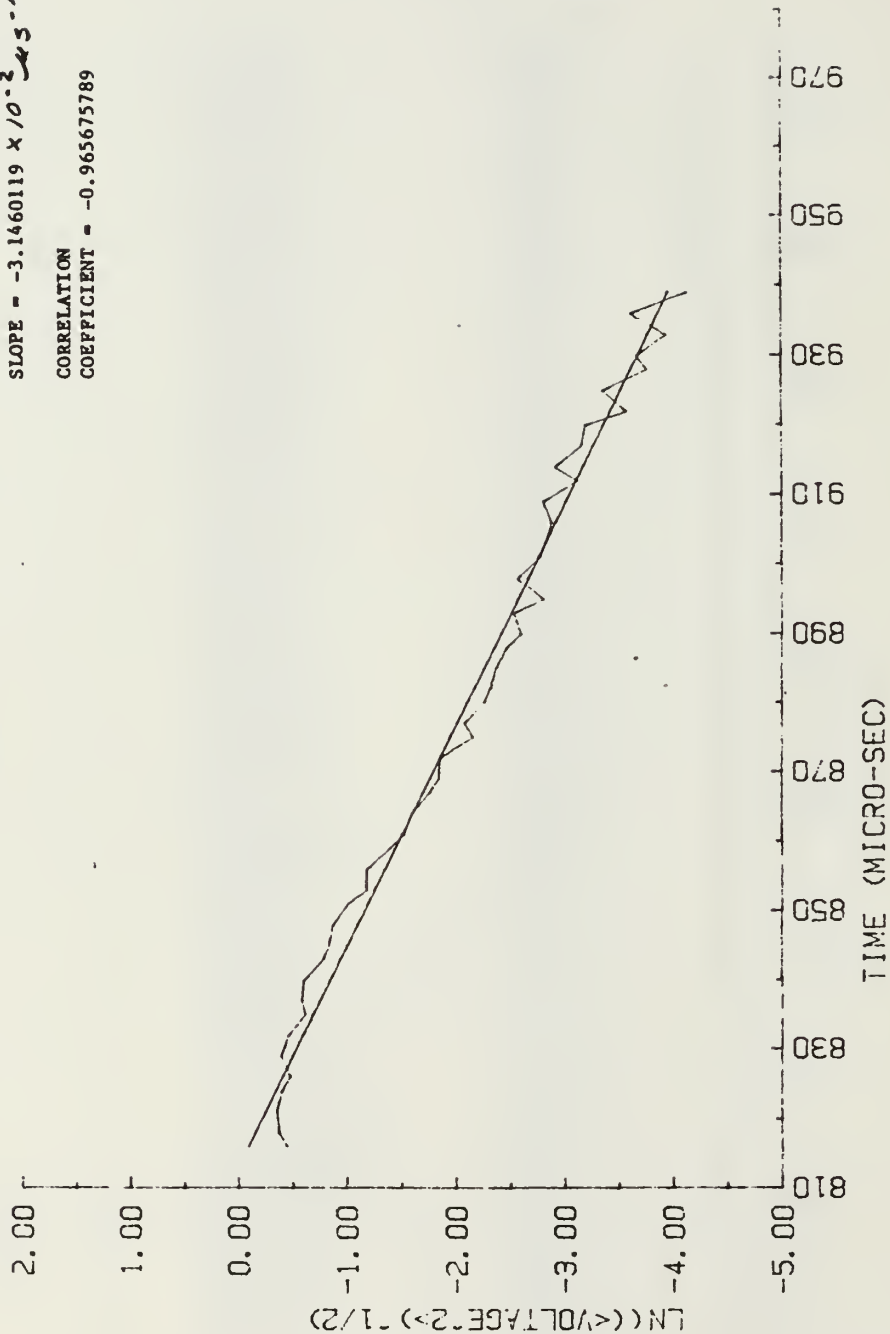
	TIME (SEC.)	VOLT
J= 0	.000816	.63647171
J= 1	.000818	.68670934
J= 2	.000821	.70203319
J= 3	.000824	.66687636
J= 4	.000826	.61608006
J= 5	.000829	.67264386
J= 6	.000832	.62724075
J= 7	.000835	.53890856
J= 8	.000837	.55637189
J= 9	.000840	.54457282
J= 10	.000843	.45660950
J= 11	.000845	.43432757
J= 12	.000848	.41456570
J= 13	.000851	.36207397
J= 14	.000853	.30559234
J= 15	.000856	.30398053
J= 16	.000859	.24790143
J= 17	.000861	.21753786
J= 18	.000864	.20195197
J= 19	.000867	.17177241
J= 20	.000869	.15779354
J= 21	.000872	.15518454
J= 22	.000875	.11536187
J= 23	.000877	.12406160
J= 24	.000880	.10410226
J= 25	.000882	.09816313
J= 26	.000885	.09290533
J= 27	.000888	.08415153
J= 28	.000890	.07392834
J= 29	.000893	.07903265
J= 30	.000895	.05997733
J= 31	.000898	.07615405
J= 32	.000901	.06199226
J= 33	.000903	.05896643
J= 34	.000906	.05559856
J= 35	.000909	.06012121
J= 36	.000912	.04392175
J= 37	.000914	.05391549
J= 38	.000917	.04228664
J= 39	.000920	.04068857
J= 40	.000922	.02782876
J= 41	.000925	.03483906
J= 42	.000928	.02314044
J= 43	.000930	.02542361
J= 44	.000933	.01934425
J= 45	.000936	.02685070
J= 46	.000939	.01602248
J= 47	.000942	.02043233
J= 48	.000944	.01098180
J= 49	.000947	.01932977
J= 50	.000950	.01244990
J= 51	.000953	.02127346
J= 52	.000956	.01371568
J= 53	.000958	.02376300
J= 54	.000961	.01977372
J= 55	.000964	.02856011
J= 56	.000967	.02011765
J= 57	.000969	.02471194
J= 58	.000972	.01903365

DATA2

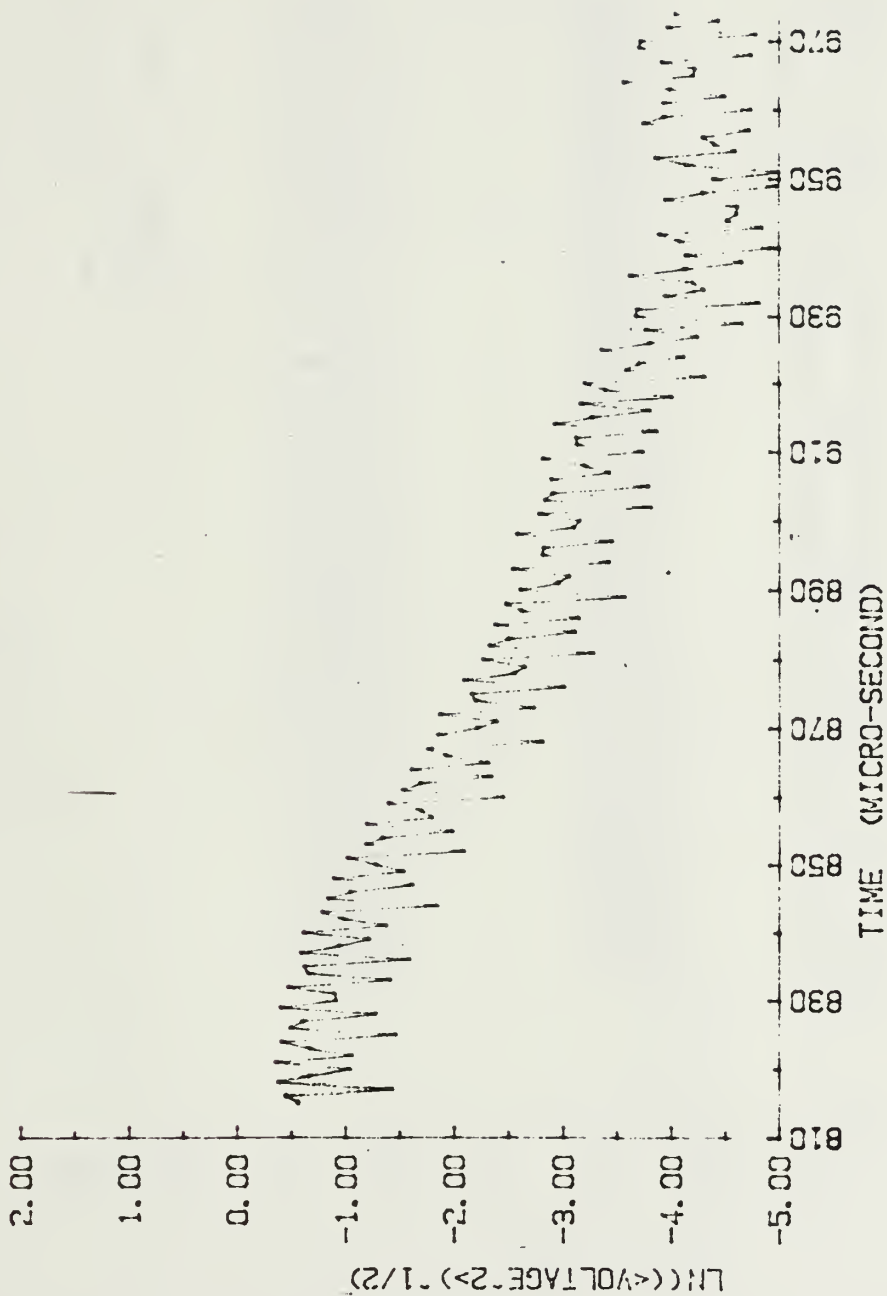
SLOPE = $-3.1460119 \times 10^{-2}$ *45-1*

CORRELATION

COEFFICIENT = -0.965675789



DATA2



DATA5

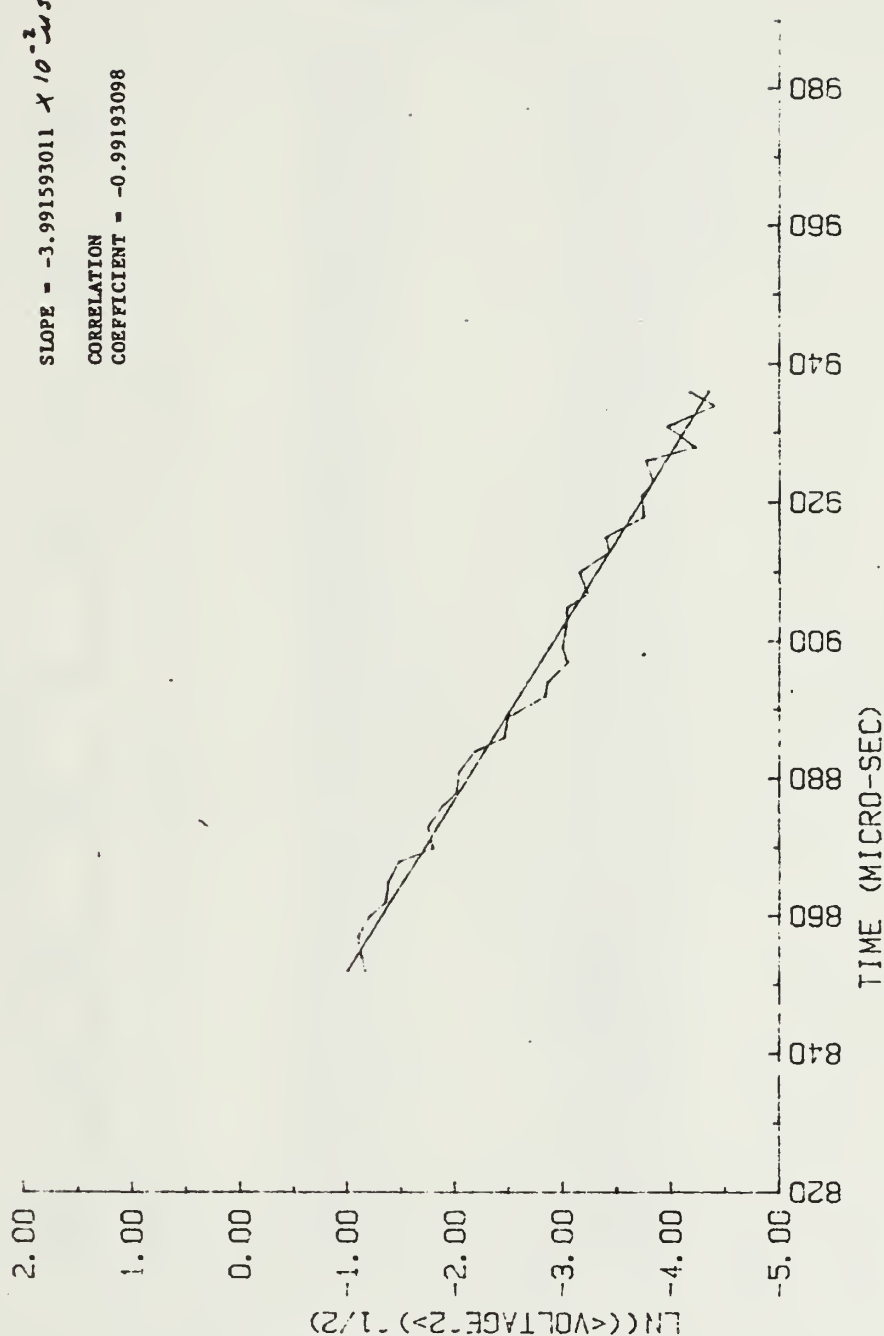
LOCAL MAXIMA

	TIME (SEC.)	VOLT
J= 0	.000852	.30892374
J= 1	.000854	.31977533
J= 2	.000857	.33199967
J= 3	.000860	.29787944
J= 4	.000862	.25730970
J= 5	.000865	.25062865
J= 6	.000868	.22680622
J= 7	.000870	.16560574
J= 8	.000873	.17395344
J= 9	.000876	.15221872
J= 10	.000878	.13277869
J= 11	.000881	.12960988
J= 12	.000884	.11217362
J= 13	.000886	.08519671
J= 14	.000889	.08202792
J= 15	.000892	.05833867
J= 16	.000894	.05723163
J= 17	.000897	.04735462
J= 18	.000899	.04970070
J= 19	.000902	.04799667
J= 20	.000905	.04755439
J= 21	.000907	.03948544
J= 22	.000910	.04260728
J= 23	.000913	.03224872
J= 24	.000915	.03359196
J= 25	.000918	.02352998
J= 26	.000921	.02405203
J= 27	.000923	.02148302
J= 28	.000926	.02309026
J= 29	.000928	.01456846
J= 30	.000931	.01894149
J= 31	.000934	.01216799
J= 32	.000936	.01524926
J= 33	.000939	.00536843
J= 34	.000941	.00569912
J= 35	.000945	.00736206
J= 36	.000948	.00413521
J= 37	.000951	.01268779
J= 38	.000954	.00887919
J= 39	.000956	.01025671
J= 40	.000959	.00398748
J= 41	.000962	.00669477

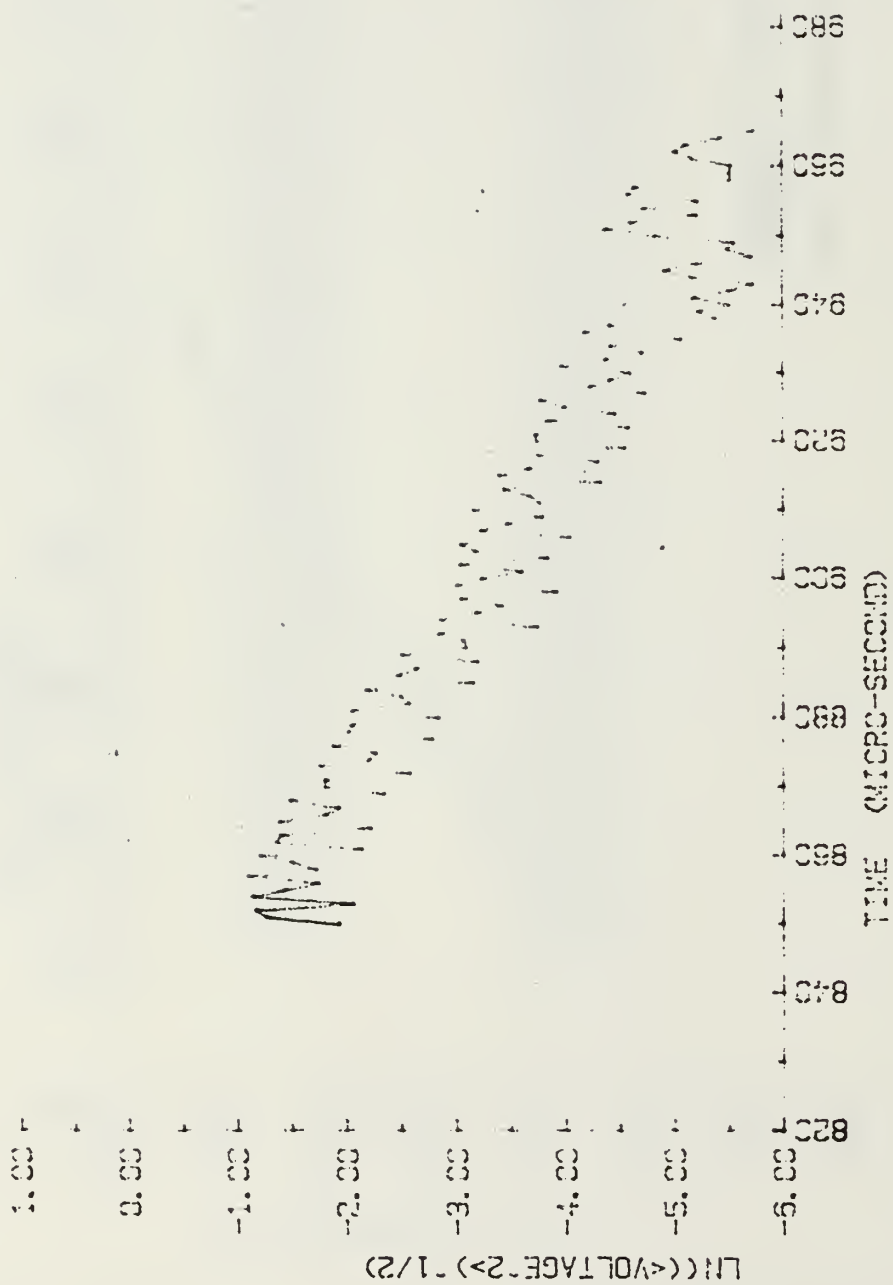
DATAS

SLOPE = $-3.991593011 \times 10^{-2} \mu s^{-1}$

CORRELATION
COEFFICIENT = -0.99193098



DATAS



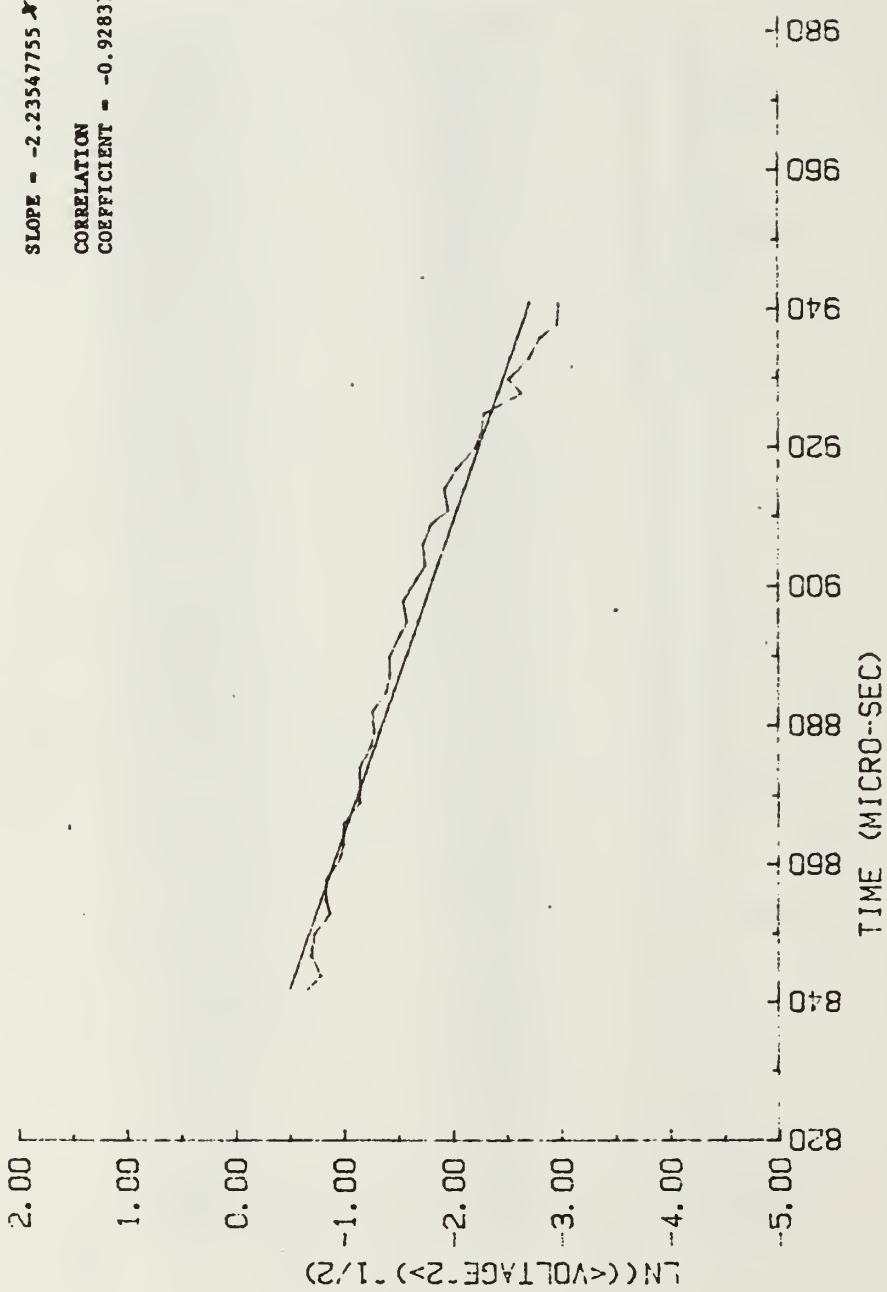
DATA12

LOCAL MAXIMA

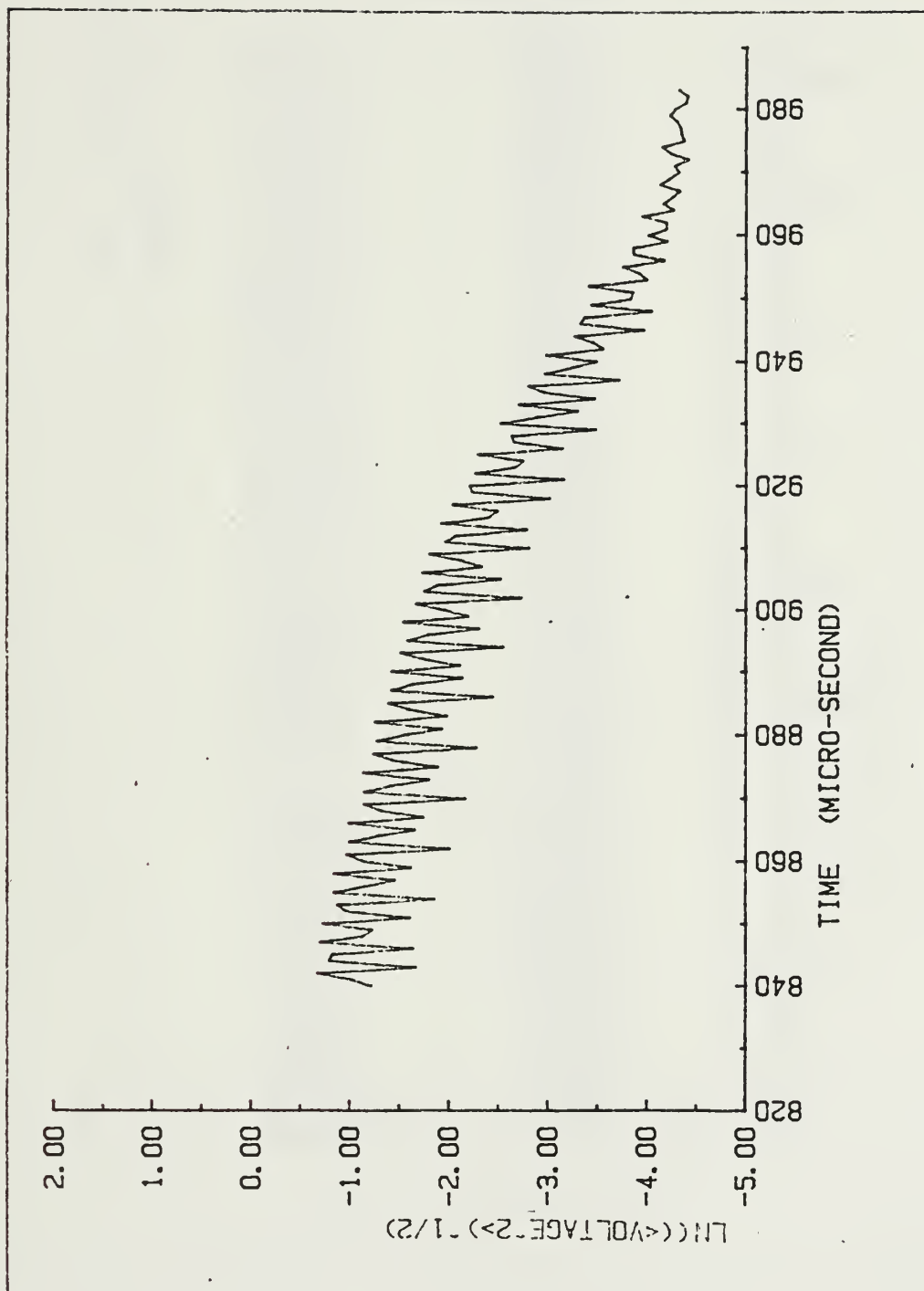
	TIME (SEC.)	VOLT
J= 0	.000842	.51143252
J= 1	.000844	.45515512
J= 2	.000847	.49761029
J= 3	.000850	.48393681
J= 4	.000853	.41767782
J= 5	.000855	.43380745
J= 6	.000858	.43167242
J= 7	.000861	.37847795
J= 8	.000863	.36895122
J= 9	.000866	.37085927
J= 10	.000869	.31776186
J= 11	.000871	.31723461
J= 12	.000874	.32058447
J= 13	.000877	.28823428
J= 14	.000879	.27889586
J= 15	.000882	.28351705
J= 16	.000885	.24864774
J= 17	.000887	.24120448
J= 18	.000890	.24103962
J= 19	.000893	.22059383
J= 20	.000895	.20647034
J= 21	.000898	.21414131
J= 22	.000901	.18922119
J= 23	.000903	.17416176
J= 24	.000906	.17814000
J= 25	.000909	.16489542
J= 26	.000911	.14071105
J= 27	.000914	.14640847
J= 28	.000917	.13048716
J= 29	.000920	.10982805
J= 30	.000922	.10438199
J= 31	.000925	.10111152
J= 32	.000928	.07178203
J= 33	.000930	.08052602
J= 34	.000933	.06700940
J= 35	.000936	.06069432
J= 36	.000938	.05167088
J= 37	.000941	.05097960
J= 38	.000944	.03818796
J= 39	.000946	.03599167
J= 40	.000949	.03224035
J= 41	.000952	.03305874
J= 42	.000955	.02339573
J= 43	.000958	.02101047
J= 44	.000960	.01809420
J= 45	.000963	.01920260
J= 46	.000965	.01550806
J= 47	.000968	.01601062
J= 48	.000971	.01384919
J= 49	.000974	.01571305

DATA12

SLOPE = $-2.23547755 \times 10^{-2} \text{ sec}^{-1}$
CORRELATION
COEFFICIENT = -0.9283714



DATA12



DATA13

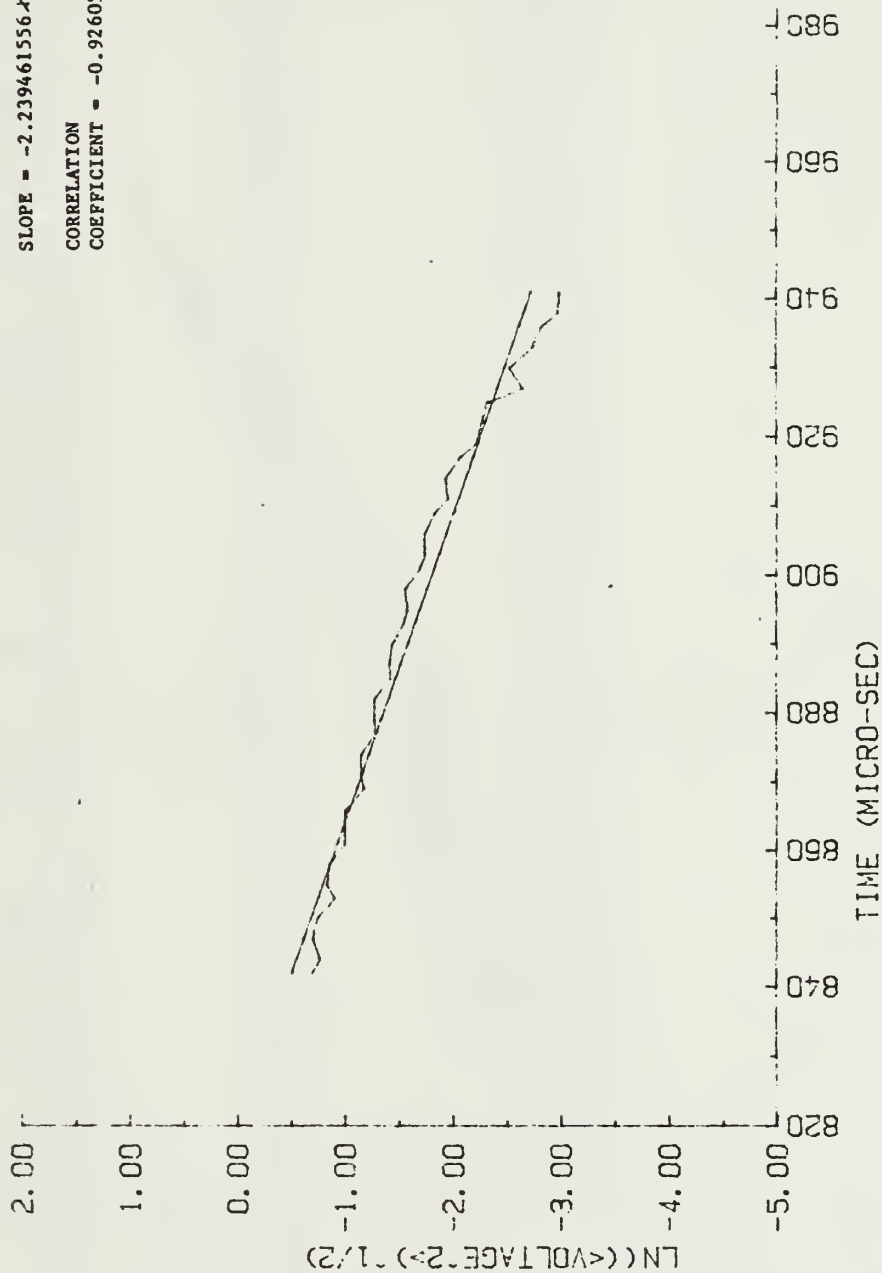
LOCAL MAXIMA

	TIME (SEC.)	VOLT
J= 0	.000842	.49913686
J= 1	.000844	.46259928
J= 2	.000847	.49610785
J= 3	.000850	.47599414
J= 4	.000853	.40373306
J= 5	.000855	.43505798
J= 6	.000858	.42462047
J= 7	.000861	.36693566
J= 8	.000863	.36960317
J= 9	.000866	.36574759
J= 10	.000869	.30842876
J= 11	.000871	.31796839
J= 12	.000874	.31615850
J= 13	.000877	.27968643
J= 14	.000879	.28068746
J= 15	.000882	.28086288
J= 16	.000885	.24147640
J= 17	.000887	.24417576
J= 18	.000890	.23726156
J= 19	.000893	.21405798
J= 20	.000895	.20650182
J= 21	.000898	.21123269
J= 22	.000901	.18393023
J= 23	.000903	.17552538
J= 24	.000906	.17617869
J= 25	.000909	.16110012
J= 26	.000911	.14185838
J= 27	.000914	.14552567
J= 28	.000917	.12739878
J= 29	.000919	.10946625
J= 30	.000922	.10387396
J= 31	.000925	.09897863
J= 32	.000927	.07104794
J= 33	.000930	.08049981
J= 34	.000933	.06514699
J= 35	.000936	.05969003
J= 36	.000938	.05119512
J= 37	.000941	.05037321
J= 38	.000944	.03716396
J= 39	.000946	.03737245
J= 40	.000949	.03230666
J= 41	.000952	.03342813
J= 42	.000955	.02316635
J= 43	.000957	.02210927
J= 44	.000960	.01818516
J= 45	.000963	.01895706
J= 46	.000965	.01550000
J= 47	.000968	.01775303
J= 48	.000971	.01434922
J= 49	.000974	.01623114
J= 50	.000976	.01383944

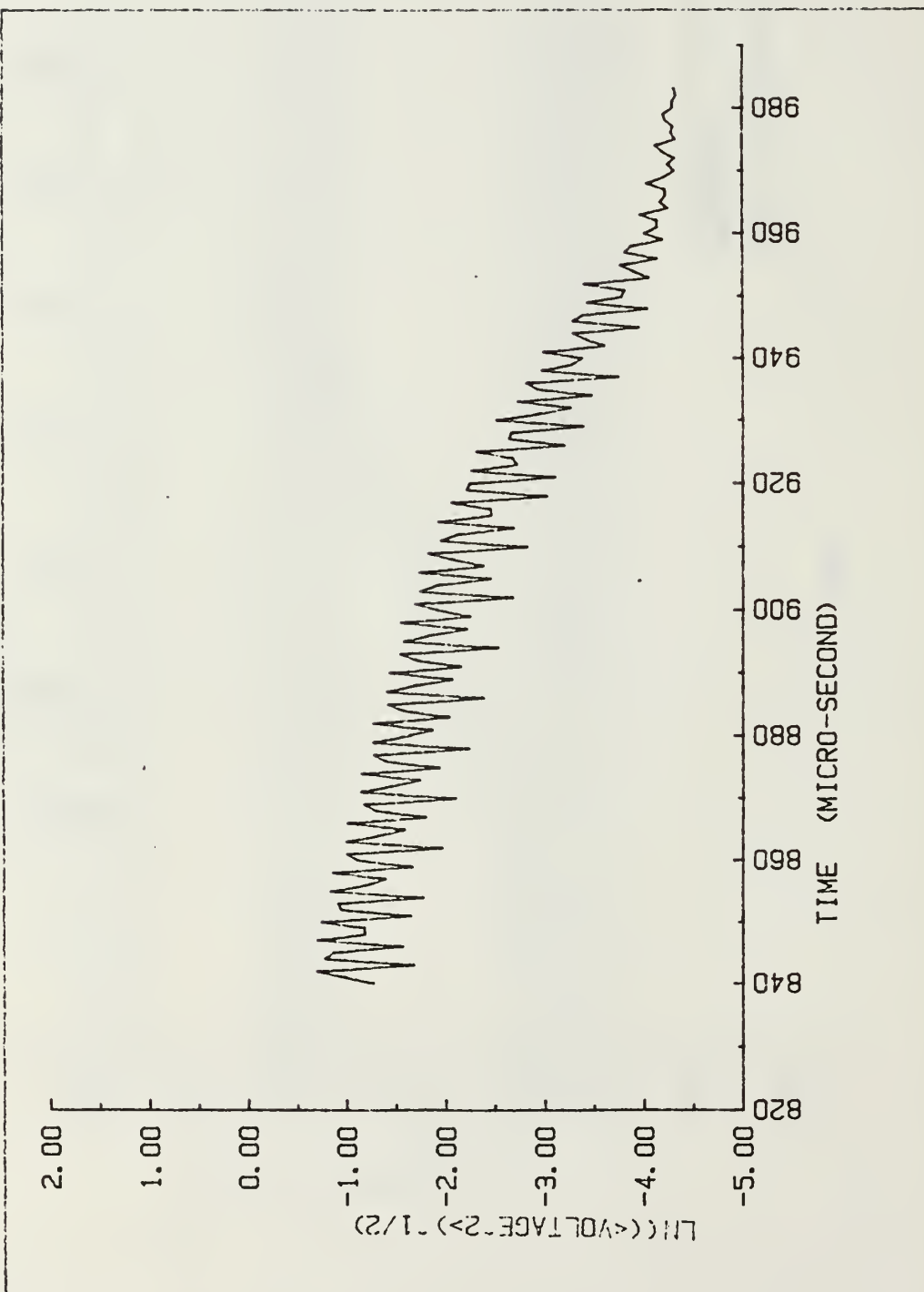
DATA13

SLOPE = $-2.239461556 \times 10^{-2} \text{ sec}^{-1}$

CORRELATION
COEFFICIENT = -0.9260575



DATA13



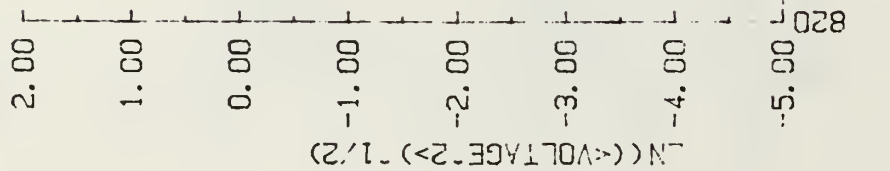
DATA14

LOCAL MAXIMA

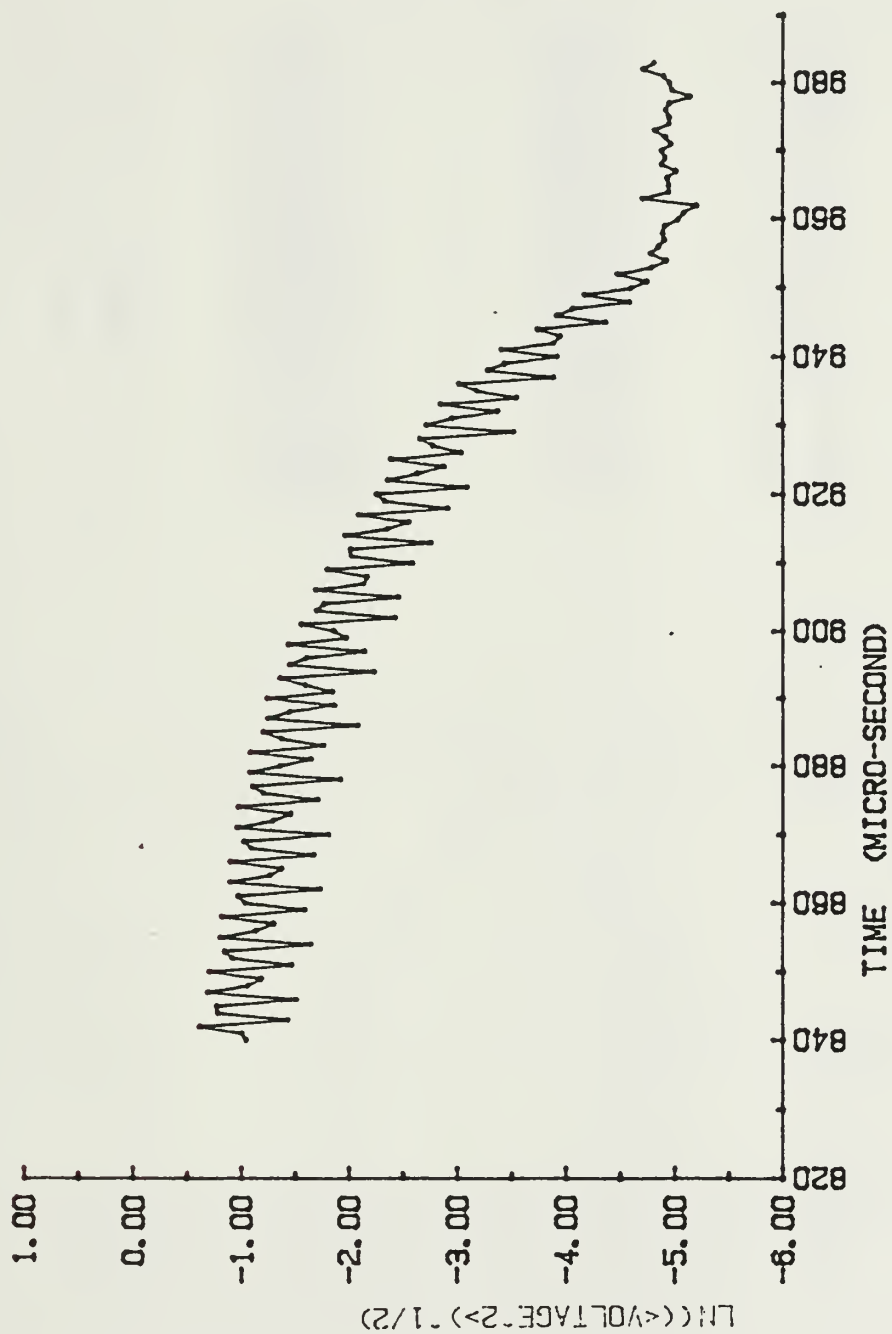
	TIME (SEC.)	VOLT
J= 0	.000842	.54045536
J= 1	.000845	.45899455
J= 2	.000847	.50422217
J= 3	.000850	.49332001
J= 4	.000853	.42883796
J= 5	.000855	.44724714
J= 6	.000858	.44041571
J= 7	.000861	.37797354
J= 8	.000863	.40769351
J= 9	.000866	.40645049
J= 10	.000869	.35724781
J= 11	.000871	.38274273
J= 12	.000874	.37784653
J= 13	.000877	.33052988
J= 14	.000879	.34012645
J= 15	.000882	.33712312
J= 16	.000885	.29928248
J= 17	.000887	.28822214
J= 18	.000890	.28938901
J= 19	.000893	.25609764
J= 20	.000895	.23441843
J= 21	.000898	.23726778
J= 22	.000901	.21052791
J= 23	.000903	.18255410
J= 24	.000906	.18451016
J= 25	.000909	.16501515
J= 26	.000912	.13276295
J= 27	.000914	.14031393
J= 28	.000917	.12374975
J= 29	.000920	.10439349
J= 30	.000922	.09439280
J= 31	.000925	.09172786
J= 32	.000928	.06992853
J= 33	.000930	.06643794
J= 34	.000933	.05817216
J= 35	.000936	.04903060
J= 36	.000938	.03776242
J= 37	.000941	.03313608
J= 38	.000944	.02387467
J= 39	.000946	.01994994
J= 40	.000949	.01549193
J= 41	.000952	.01140175
J= 42	.000955	.00836660
J= 43	.000958	.00748331
J= 44	.000963	.00905539
J= 45	.000966	.00721110
J= 46	.000968	.00761577
J= 47	.000970	.00761577
J= 48	.000973	.00812404
J= 49	.000976	.00734847

DATA14

SLOPE = -2.53586537 x 10⁻² sec⁻¹
CORRELATION
COEFFICIENT = -0.8355922



DATA14



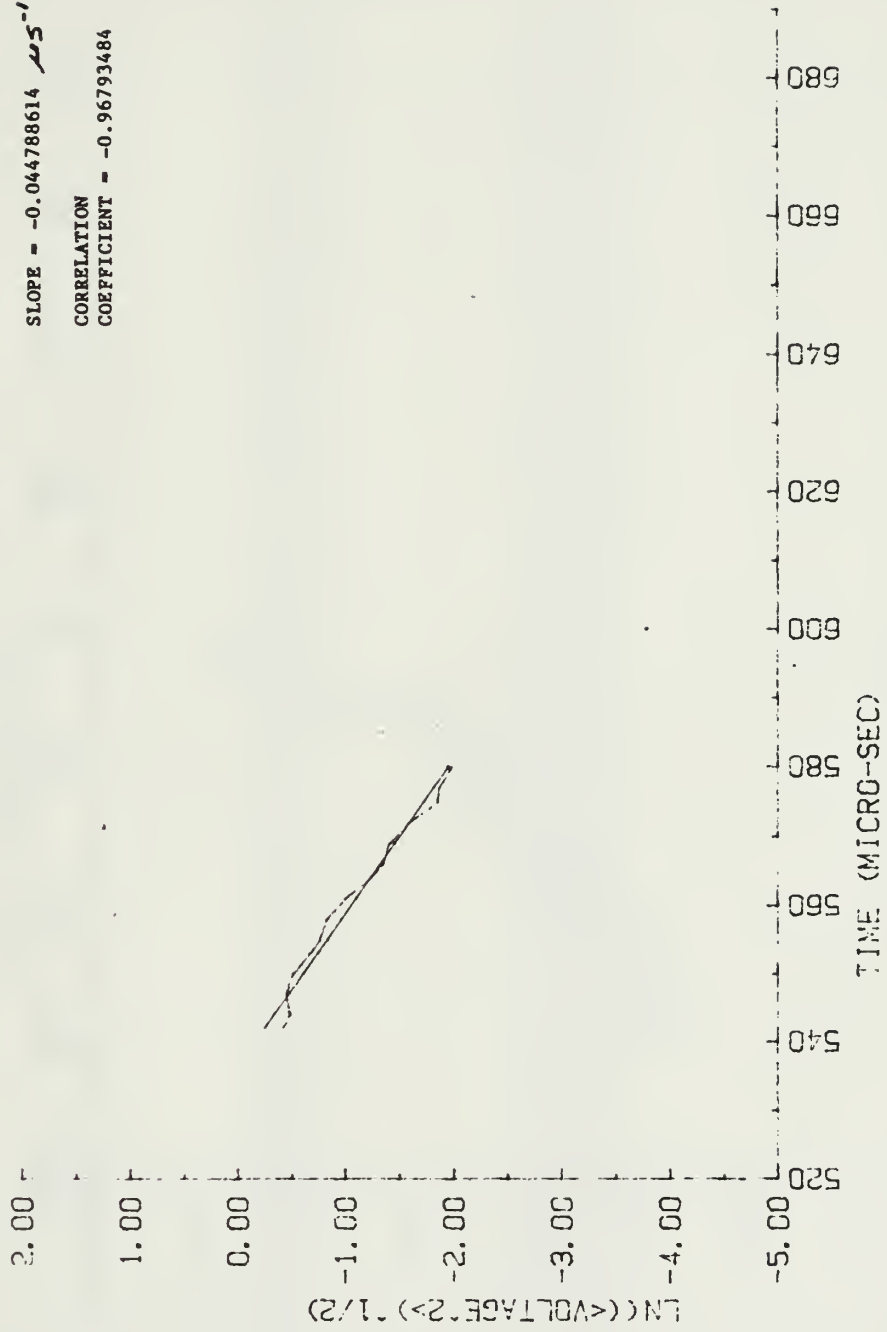
DATA15

LOCAL MAXIMA

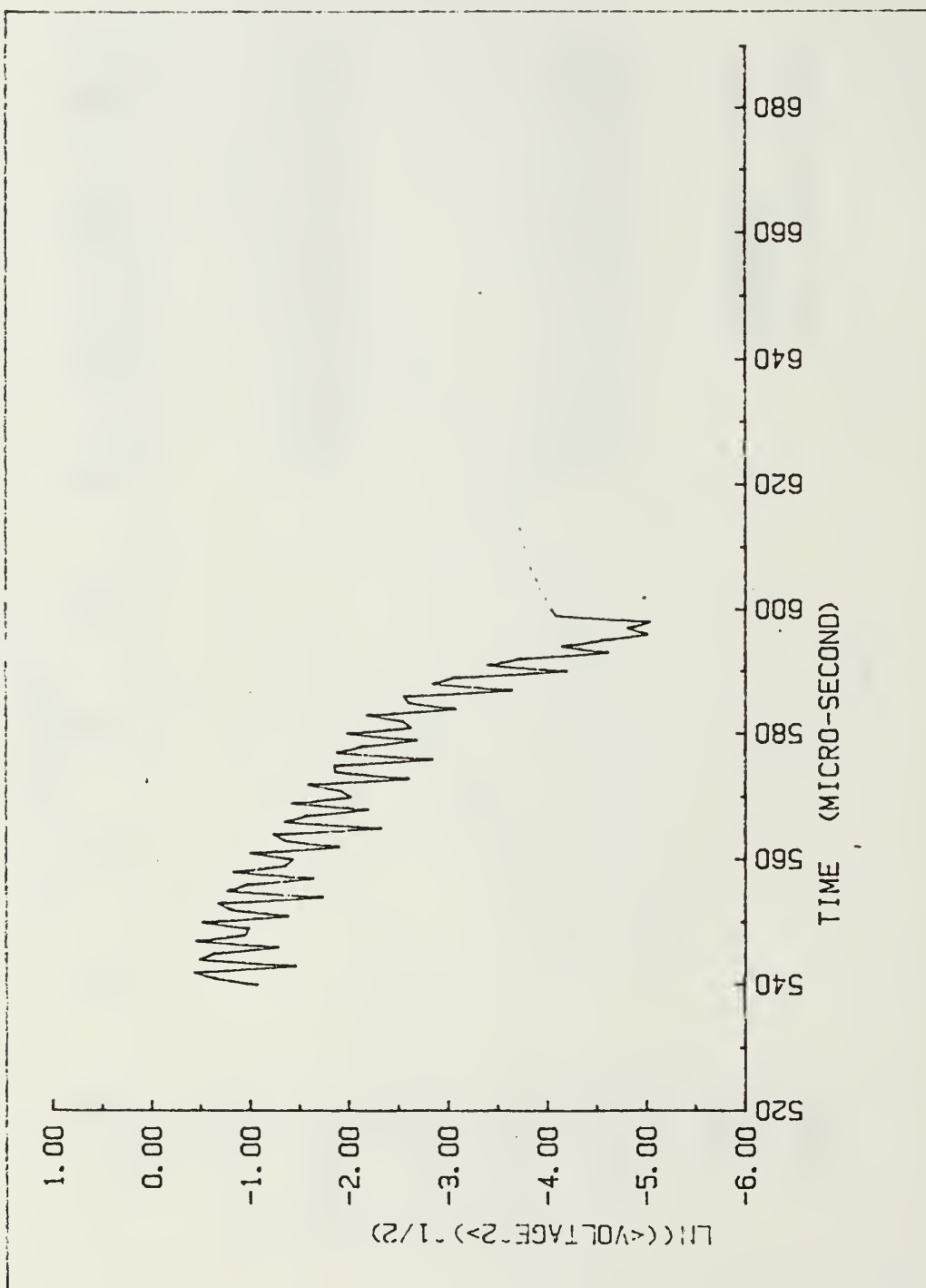
	TIME (SEC.)	VOLT
J= 0	.000542	.65138314
J= 1	.000544	.61425402
J= 2	.000547	.63677312
J= 3	.000550	.59729390
J= 4	.000553	.51099315
J= 5	.000555	.46395689
J= 6	.000558	.43594954
J= 7	.000561	.36813584
J= 8	.000564	.28952029
J= 9	.000566	.25883199
J= 10	.000569	.24260256
J= 11	.000572	.20407842
J= 12	.000575	.15612815
J= 13	.000577	.15282016
J= 14	.000580	.13717143
J= 15	.000583	.11277411
J= 16	.000586	.07749839
J= 17	.000588	.05820653
J= 18	.000591	.03358571
J= 19	.000594	.01581139

DATA15

SLOPE = -0.044788614 μS^{-1}
 CORRELATION
 COEFFICIENT = -0.96793484



DAT15

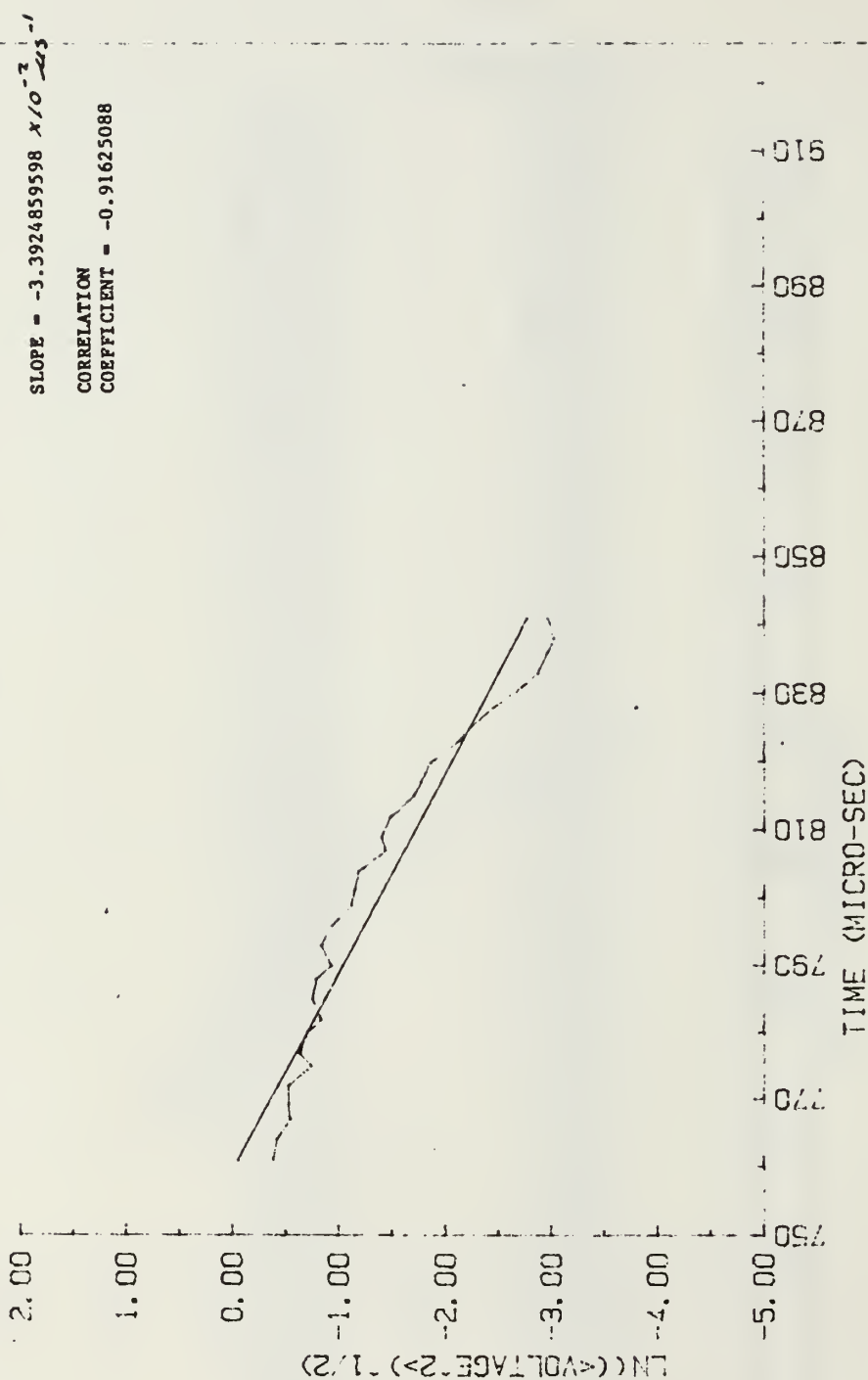


DATA16

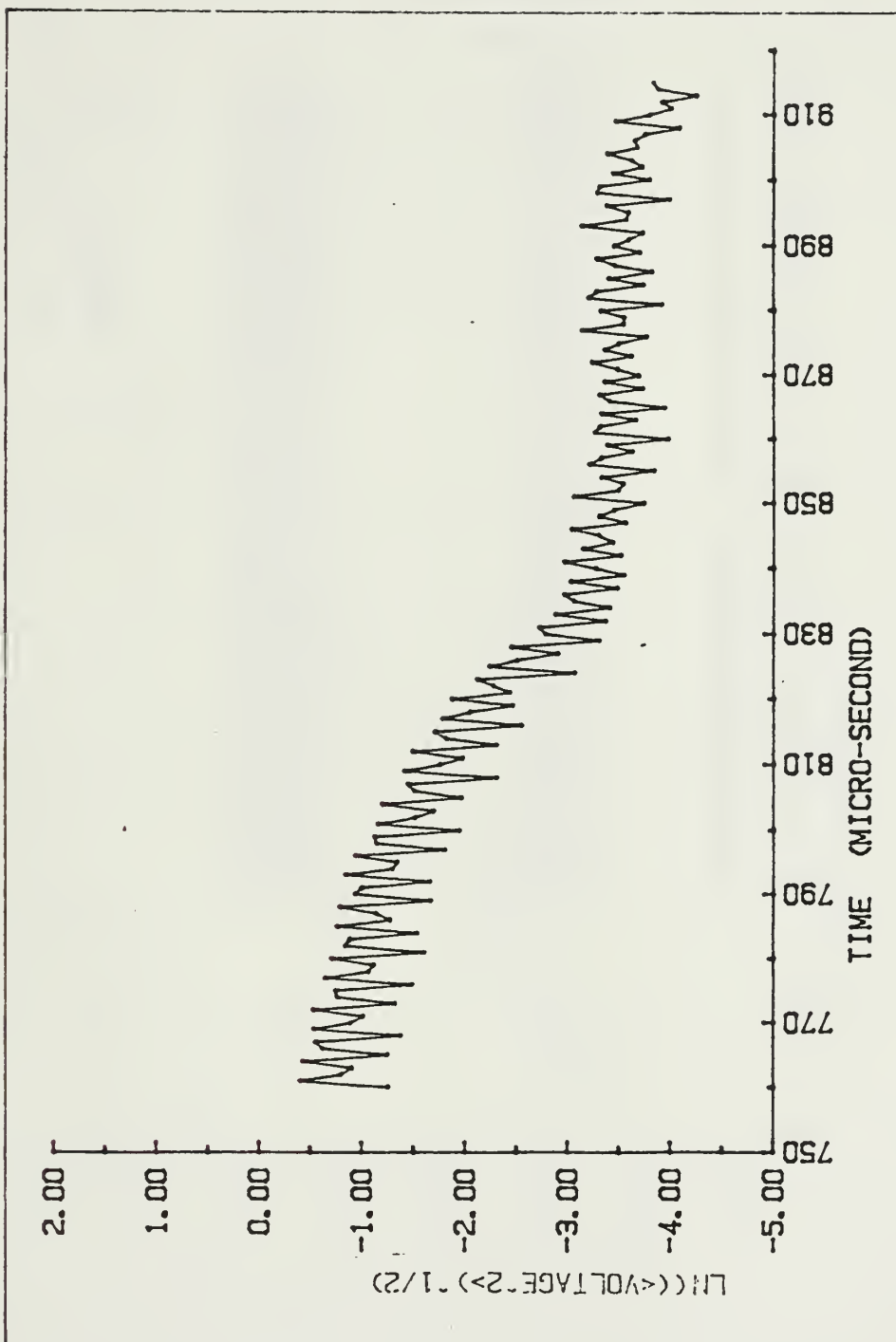
LOCAL MAXIMA

	TIME (SEC.)	VOLT
J= 0	.000761	.67368242
J= 1	.000764	.65251513
J= 2	.000767	.57663160
J= 3	.000769	.58674015
J= 4	.000772	.58829924
J= 5	.000775	.47568897
J= 6	.000777	.52818179
J= 7	.000780	.49106415
J= 8	.000782	.43248121
J= 9	.000785	.46876007
J= 10	.000788	.45445352
J= 11	.000790	.39325310
J= 12	.000793	.43202778
J= 13	.000796	.39054833
J= 14	.000799	.32404938
J= 15	.000801	.31501111
J= 16	.000804	.30213904
J= 17	.000807	.23520204
J= 18	.000809	.24467121
J= 19	.000812	.22517549
J= 20	.000815	.18150482
J= 21	.000817	.16956415
J= 22	.000820	.15437616
J= 23	.000823	.12000000
J= 24	.000825	.10703271
J= 25	.000828	.08597674
J= 26	.000831	.06572671
J= 27	.000833	.05635601
J= 28	.000836	.05145872
J= 29	.000838	.04833218
J= 30	.000841	.05130302
J= 31	.000843	.04289522
J= 32	.000846	.04783304
J= 33	.000848	.03676955
J= 34	.000851	.04698936
J= 35	.000854	.03588872
J= 36	.000856	.04039802
J= 37	.000859	.03394113
J= 38	.000861	.03847077
J= 39	.000864	.03600000
J= 40	.000867	.03655133
J= 41	.000869	.03487119
J= 42	.000872	.03939543
J= 43	.000874	.03475629
J= 44	.000877	.04354308
J= 45	.000880	.03622154
J= 46	.000882	.04089010
J= 47	.000885	.03358571
J= 48	.000888	.03762978
J= 49	.000890	.03174902
J= 50	.000893	.04363485
J= 51	.000896	.03417601
J= 52	.000898	.03762978
J= 53	.000901	.03212476
J= 54	.000904	.03405877
J= 55	.000906	.02592296
J= 56	.000909	.03149603

DATA16



DATA16



DATA17

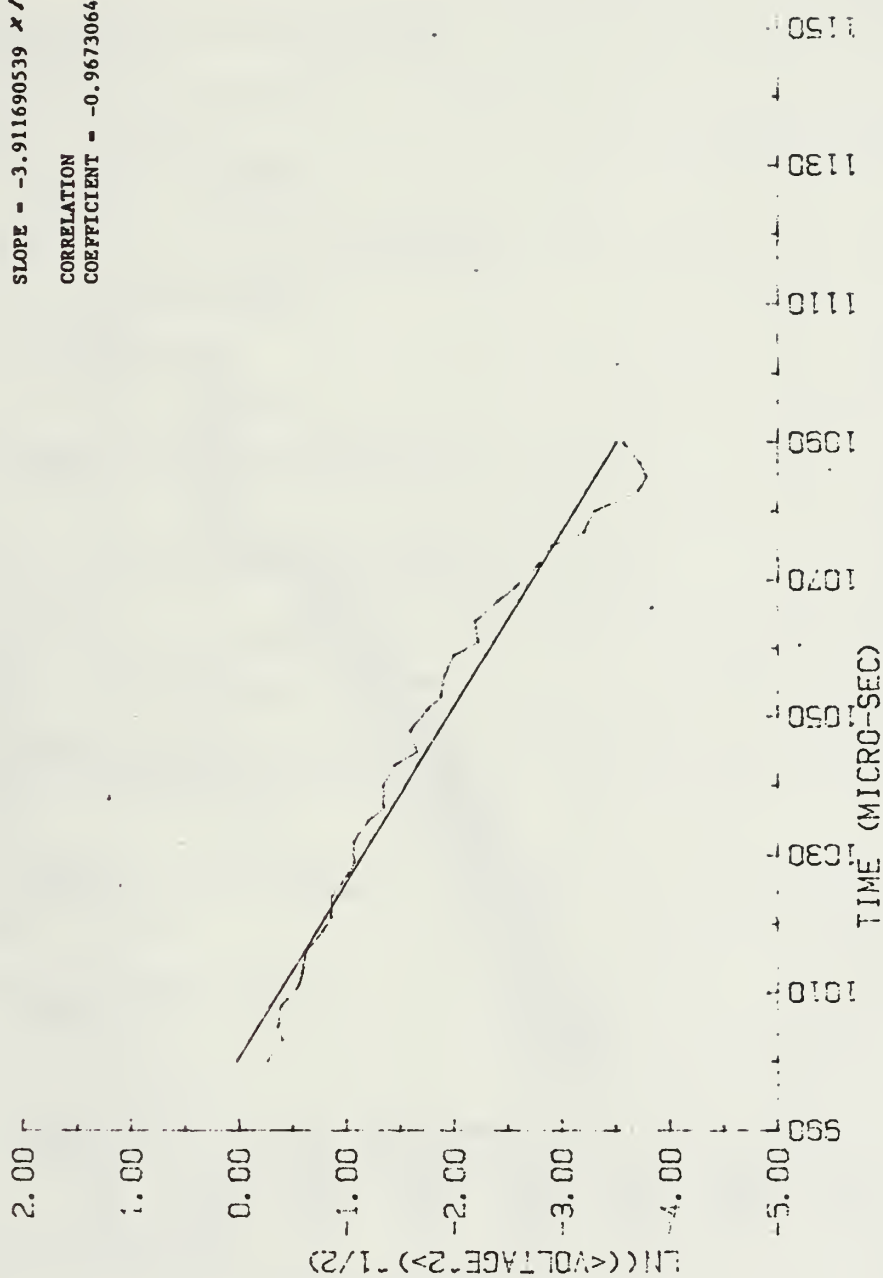
LOCAL MAXIMA

	TIME (SEC.)	VOLT
J= 1	.001003	.66241377
J= 2	.001005	.69465963
J= 3	.001008	.67388426
J= 4	.001011	.57271983
J= 5	.001013	.55145625
J= 6	.001016	.53675320
J= 7	.001019	.45745382
J= 8	.001021	.42155901
J= 9	.001024	.42019995
J= 10	.001027	.36488902
J= 11	.001029	.33958799
J= 12	.001032	.34191227
J= 13	.001035	.29906521
J= 14	.001037	.25879722
J= 15	.001040	.26047649
J= 16	.001043	.23394016
J= 17	.001045	.19047310
J= 18	.001048	.20325354
J= 19	.001051	.17385051
J= 20	.001053	.15252541
J= 21	.001056	.14775656
J= 22	.001059	.13538094
J= 23	.001061	.10829589
J= 24	.001064	.11131936
J= 25	.001067	.09006664
J= 26	.001069	.07668116
J= 27	.001072	.06273735
J= 28	.001075	.05491812
J= 29	.001077	.04049691
J= 30	.001080	.03676955
J= 31	.001083	.02449490
J= 32	.001085	.02262742
J= 33	.001087	.02400000
J= 34	.001090	.02800000
J= 35	.001092	.02078461
J= 36	.001095	.01959592
J= 37	.001097	.02349468

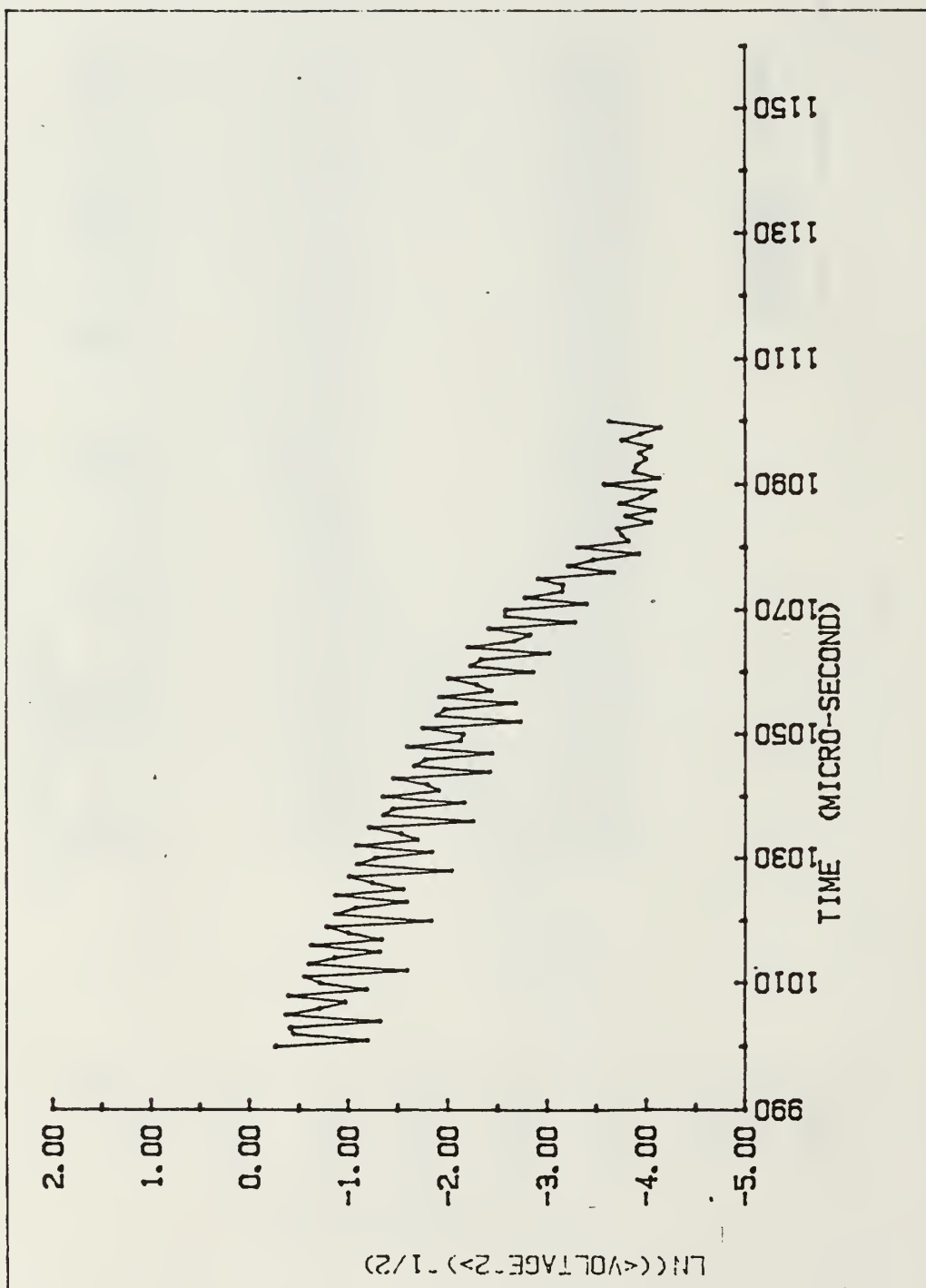
DATA17

SLOPE = $-3.911690539 \times 10^{-2} \mu s^{-1}$

CORRELATION
COEFFICIENT = -0.9673064



DATA17



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